

**An agent-based simulation of land-use  
in a swidden agricultural landscape of the  
Kantu' in Kalimantan, Indonesia**

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# Declaration

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The work presented in this thesis is my own original work, except where otherwise acknowledged in the text.



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# Abstract

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Although the ecological effects of human actions on landscapes have long been studied, less attention has been paid to studies of the socio-cultural and economic forces that underlie the human actions. Land-use modelling is a useful technique to study the interactions between socio-cultural, economic and ecological factors affecting landscape dynamics within a single research framework. However, existing models seldom address the land-use issues from a household perspective, despite the well-known fact that a household is the main unit or ‘agent’ of land-use decisions in most agricultural landscapes.

The objective of this study was to develop a modelling framework that integrates the demographic, socio-cultural, economic and ecological factors affecting landscape dynamics so that (1) the agents of land-use decisions are explicitly represented, and (2) land-cover changes are spatially simulated. The model was designed to be used in regions where households are the main agents of land-use decisions. The main modelling approach adopted in this study is the individual-based or microsimulation approach, which is used to simulate household dynamics. A landscape used for swidden cultivation by the Kantu’ community in Kalimantan was selected as a case study. The Kantu’ community was chosen because there are extensive existing socio-cultural data for this community and also other swidden communities in the region with whom the Kantu’ share many common socio-cultural elements. The land-use model takes into account the socio-cultural practices of the Kantu’ including the marriage, land tenure and land inheritance systems. The model simulates the land-use decisions made by individual households on ‘what to plant’ and ‘where to plant’ and simulates the consequences of those decisions on the landscape as well as the economic welfare of the households. The model deals with swidden cultivation of rice, and the planting and tapping of rubber.

The structure of the model consists of four main modules simulating population dynamics, land-use decision-making, production evaluation, and vegetation dynamics. The population dynamics module stochastically simulates the birth, death and marriage of individual persons and organises the persons into households. The land-use decision-making module simulates the site selection, the setting of cultivation schedule, the execution of various cultivation tasks (e.g. slashing, felling and harvesting), and the process of labour hiring. The production evaluation module is used to determine whether the demand for rice and cash within each household has been satisfied. The process of tapping rubber, including share-tapping arrangements, is also simulated in this module. A procedure is used to simulate rice and cash borrowing among the households. The vegetation dynamics module simulates the succession of vegetation following swidden abandonment. The overall model operates on an annual time step, but the execution of cultivation tasks and tapping rubber both use a daily time step.

The model was run in a hypothetical landscape with an area of 12.5 km<sup>2</sup>, which is initially covered by primary forest. The initial population consisted of 63 people organised into nine households. The results of simulations show that the population grows at about 2.6 % per annum. As the population increases, the primary forest declines and is usually lost after about 45 years. Over this period, the landscape tends to be progressively dominated by shrubland, but the rates at which these trends occur vary depending on the precise assumptions and parameterisations of the model. In this model, clearing primary forest is the primary means of households' to acquire ownership to land and the ability of a household to accumulate land holdings largely depends on the demographic composition of the household. In particular, the households that accumulate more land tend to be those that were formed early, have many sons and experience fewer out-marriages. As the community develops, land-holding inequality emerges resulting in differential access to productive land amongst the households, which in turn determines the ability of households to satisfy its demand for rice. In general, this study demonstrates that population pressure in a swidden agriculture system leads to decreasing fallow period, declining rice production and thus increasing the role of cash income from rubber for fulfilling the households' overall consumption needs. The decreasing fallow is a major concern, since it could lead to deterioration of the environment. However, this study shows that, even without any technological improvement, the potentially negative impacts of swidden cultivation associated with declining fallow length can be lessened by modifying the agricultural strategy, i.e. focusing on tapping rubber during periods with high rubber price.

Modelling changes in landscapes is an important step in developing land management strategies in the face of rapidly changing socio-economic conditions, as well as other changes, e.g. climate change. Techniques exist to simulate the location and impacts of 'natural processes' such as fires and other disturbances, and consequential changes in land cover. The significance of socio-cultural factors in affecting land-use and landscape development is well recognised but only rarely implemented in such models. This study has demonstrated that individual-based modelling is an effective approach to integrating the demographic, socio-cultural and economic factors in land-use modelling. The fact that the individual-based approach represents the heterogeneous nature of households suggests that this approach can be a valuable tool for policy analysis, since it allows not only predictions of the full impacts of policies but also the associated distributional impacts, i.e. who will be adversely effected.

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# Chapter 1

## Introduction

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### 1.1 Preface

I started this research project with an interest in the role of disturbances in affecting the dynamics of vegetation in tropical forest landscapes from an ecological perspective, because ecology was my training background. But I realised that in many tropical forest landscapes, especially in the developing countries, human actions on landscapes constitute the main form of disturbance. Focusing on ecological aspects alone would be of limited value without addressing the socio-cultural and economic forces behind human actions. Subsequently, the research shifted from narrowly ecological to an interdisciplinary study focusing more on elucidating and simulating human actions in altering the landscape while maintaining the ecological perspective. This thesis describes the process of developing an agent-based land-use simulation model and the use of the model to study the dynamics of a swidden agricultural landscape.

In this chapter, the research framework is outlined and a literature review of the existing models is presented. An overview of the approach used in this study is then described, followed by an outline of how the thesis is organised.

### 1.2 Research framework

Human influence on tropical landscapes extends back to the emergence of settled agriculture about 10,000 years ago. Since then, approximately 20-30 % of tropical forest landscapes worldwide have been converted to other land cover types mostly because of changes in land use (Houghton, 1994). Estimates for the South and Southeast Asia region suggest that between 34 – 38 % of the tropical forest landscape has disappeared from 1850 to 1990 (Houghton and Hackler, 1994; Richards and Flint, 1994). Another worldwide estimate of tropical deforestation suggested that 15.4 million ha of forest were deforested annually during the 1981-1991 period, i.e. approximately 2.7 % per annum (FAO, 1993). The loss of tropical



forestland cover has generally been accompanied by an increase in the area of croplands and pastures. The area of cropland worldwide more than doubled during the 1850-1990 period (Houghton, 1994) suggesting that agricultural expansion is the largest cause of landscape change. Logging is another important source of change. Apart from its immediate impact in reducing the area of tropical forest, logging activities may also speed up the agricultural expansion, because the roads needed for logging also make the forest more accessible for farming activities (e.g. Kummer and Turner II, 1994).

Tropical forests are major reserves of biodiversity and play a crucial role in maintaining ecosystem services critical to the biosphere as a whole (Noble and Dirzo, 1997). Therefore, global scale land-use changes within tropical forest landscapes have profound ecological impacts such as the loss of biodiversity through habitat loss and fragmentation (Pearson *et al.*, 1999; Pimm *et al.*, 1995; Wilson, 1988). At local scales, biodiversity is reduced following conversion of species-rich tropical forest into agricultural land-use or indirectly through habitat modification via activities like logging. In the latter case, landscape fragmentation can cause disruption of natural processes critical to the survival of species, such as disruption of seed dispersal or reduction of required breeding habitat (Dale, 1997). Another major ecological impact of land-use change is related to the role of forest as the principal store of carbon in terrestrial ecosystems. Dale (1997) estimated that forests contain approximately 90 % of the carbon stored in global vegetation. Conversion of high-biomass tropical forest to other land-uses like agriculture contributes a significant share to the increased atmospheric CO<sub>2</sub> and other greenhouse gases, which potentially leads to global warming and other climatic changes. For example, Houghton (cited by Houghton, 1994) estimated that land-use changes, mainly through deforestation, have contributed approximately 25 % to the enhanced greenhouse effect.

Understanding the linkages between the human driving forces behind land-use changes and the associated ecological effects is crucial as a basis for developing a resource management system which is capable of handling both the dynamics of the human and biophysical aspects. Understanding the role of humans in land-use change is the first key step in the process. This requires a perspective that

simultaneously considers the socio-economic, political, cultural and environmental context within which land-use decisions occur, as well as the multi-scale dimension of the issue (Turner II *et al.*, 1995).

At a global scale, population growth has been generally suggested as the ultimate driving force for most land-use changes (e.g. Allen and Barnes, 1985; Rudel, 1989) but the actual mechanism of change is complex and involves interconnections with policies, institutional context as well as economic forces (Kummer and Turner II, 1994; Meyer and Turner II, 1992; Skole *et al.*, 1994). Undoubtedly, some of the driving forces are global in nature. The international demand for tropical wood products and agriculture commodities is an example of the global economic forces driving the tropical forest conversion in many developing countries. Nevertheless, it is the local context that eventually determines the path of land-use changes in specific situations.

The understanding of human driving forces and the ecological implications could be improved when the global scale of analysis is combined with analysis at a lower spatial scale (i.e. landscape). In particular, while the global perspective is useful, it often fails to account for the local mechanisms which are responsible for determining changes in land-use (Houghton, 1994). A landscape scale of analysis permits more attention to be given to the role of agents (e.g. farming households) of the changes, as well as the associated social institutions which affect land-use and land cover change (e.g. land tenure, community organisation).

At local scales, the heterogeneous nature of land-use decisions by the 'agents' should be more apparent. For example, in an agricultural context, land-use decisions are likely to vary across households due to differences in personal objectives, natural resources and the capital available to households (Vosti and Wittcover, 1996). The agricultural strategy of a household may also change through time. In this regard, several authors have shown that the internal dynamics (i.e. changes in the structure and composition) of farming households is correlated with changes in the households' choice of land-use and labour allocation (e.g. Leinbach and Smith, 1994; Walker and Homma, 1996; Wilk, 1984). One could then speculate that there would be variation in the type and intensity of land-use across households even if the

communities as a whole were subjected to homogeneous external driving forces. Given the role of farming households as the agent of land-use change, changing circumstances (political, economic and socio-cultural) that impinge upon the households internally or externally will affect the land-use decisions and hence the land-cover dynamics (Walker, 1996). A better understanding of the dynamics of (agricultural) landscapes should therefore incorporate processes that operate at the household level.

Social institutions such as land tenure systems are frequently noted as an important factor shaping the pattern of land-use changes, but their role is rarely discussed in detail at the global level of analysis, presumably due to the enormous variation and the specific social/cultural nature of the issue. The importance of taking into account the land tenure system when analysing land-use changes is based on the fact that the land tenure system essentially regulates the access to resources; i.e., it determines 'who can' and 'who cannot' use lands for specific purposes. In some cases, it also effectively sets the limits on the types of land conversion, which can actually occur.

The latter case can be exemplified by the situation in two Iban communities in Borneo, as reported by Cramb (1989a). In one community (Nanga Taphi village), fallow lands were under community control and available at any time to all members of the community for hill-rice cultivation, but not for conversion to perennial gardens such as rubber gardens. Conversion to a rubber garden was possible only if the whole community agreed to convert fallow lands into rubber at the same time. In contrast, fallow lands were under individual household control in the other community (Batu Lintang village) and the decision on 'what to plant', including conversion to rubber, resided entirely with the landowner. Because of the rubber planting restriction, rubber holdings in Nanga Taphi were more evenly distributed than in Batu Lintang. The Nanga Taphi case in particular highlights the role of land tenure systems in regulating the allowable paths of land-use conversion.

Modelling is one of the core approaches used to study land-use changes. The use of models is convenient because experimental studies are often impractical or impossible in real landscapes (Baker, 1989b). Moreover, models can be used to study interactions between the numerous factors that can affect landscape dynamics

(e.g. ecology, physiography, socio-culture and economics), in contrast to the classical scientific (experimental) approach where each factor is studied in isolation, within a single research framework (Campbell *et al.*, 2000; Costanza *et al.*, 1993). Increasingly, models are also being used as tools to evaluate land-management alternatives that cannot be tested in realistic situations (Mladenoff and Baker, 1999). Numerous land-use/landscape models have been developed in the last 30 years. These models vary a great deal in terms of modelling approaches (e.g. empirical *vs* mechanistic, mathematical *vs* rule-based), spatial and temporal scale, and the goal of the simulation.

Our understanding of the factors affecting land-use changes has been greatly improved through the use of *statistical/empirical models*. These models are generally constructed with the aim to elucidate the important socio-economic and spatial factors that contribute to the observed spatial and temporal patterns of land-use and land cover. This is generally done by statistically establishing correlative measures between variables that are thought to be potentially important and empirically derived rates of change. The rate of change of land use can be derived from multi-temporal sequences of remotely sensed data, while conceptual models based on economic theories can be used to guide the selection of potentially important socio-economic variables (e.g. Mertens and Lambin, 2000). Many of these models have dealt with tropical deforestation and the consequent conversion to agricultural land-uses (see Kaimowitz and Angelsen, 1998 for review; Lambin, 1994). The increasing availability of remotely sensed data for many parts of the world, combined with the spread of GIS (Geographic Information Systems) technology has encouraged the use of this approach.

In another type of modelling approach, known as dynamic simulation, models attempt to simulate the interactions between the various factors affecting the dynamics of the landscape (biophysical, economic and socio-cultural) in a mechanistic way based on *a priori* understanding of a system (Lambin *et al.*, 2000). This type of model is mechanistic in a sense that it attempts to represent the underlying processes, which are expressed as sets of equations or as rules. The parameters are estimated from existing data, and for a rule-based approach, the rules are inferred from the results of other empirical studies. Thus, mechanistic models are

to some extent empirical (Elston and Buckland, 1993). Howell (1978) summarised one advantage of this approach when saying that it “forces one to specify precisely how a process might work and permits one to explore possible outcomes of such a process systematically”.

Models of this type are usually spatially explicit and operate at the landscape scale. Some models deal mainly with biophysical/ecological aspects of forest landscapes with restricted and indirect role of humans (e.g. Costanza *et al.*, 1990; Liu *et al.*, 1999; Mladenoff *et al.*, 1996; Urban *et al.*, 1991). Generally, succession is the main process represented in the ecological models where natural (e.g. fire, tree-fall) or man-induced (e.g. timber harvest) disturbances play an important role in directing the pathway of vegetation change. Other dynamic simulation landscape models incorporate the human factor to a greater extent, primarily through the modification of the landscape for agricultural land-use (e.g. Dale *et al.*, 1993; Gilruth *et al.*, 1995; Thornton and Jones, 1998; Wilkie and Finn, 1988). Socio-economic aspects of land-use tend to be more elaborately represented in these models. The feature distinguishing them from ‘ecological’ models and empirical/statistical models is that the ‘agents’ of land-use change are explicitly represented, namely the individual farming household. The dynamics of the landscape are assumed to be a function of land-use decisions about the timing, extent and location of cultivation. Thus, landscape changes over time are a geographical expression of a large number of individual land-use decisions made at different times (Harvey, 1966). Land-use dynamic simulation models appear to be reasonably successful in linking the economic and ecological aspects of landscape dynamics within a single research framework. However, many of the existing land-use models emphasise the biophysical and economic processes and either do not represent, or represent very crudely, processes involving individual households, land tenure and social customs.

The objective of this study was to develop a modelling framework that integrates the demographic, socio-cultural, economic and ecological factors affecting landscape dynamics in such a way that (1) the agents of land-use decisions are explicitly represented, and (2) land-cover changes are spatially simulated. It was designed for applications in regions where households are the main agents of land-use decisions. In doing so, I decided early on to adopt the dynamic simulation approach but to

incorporate a more detailed representation of the human component. In this approach, the community is represented as a collection of individual persons who are grouped into individual households. The innovation of this approach is that it explicitly simulates the dynamics of the household developmental cycle including changes in both the number and age structure of households resulting from births, deaths and marriages. Originally, the basic idea for this approach came from the individual-based models used in ecology (e.g. Botkin *et al.*, 1972; or Urban and Shugart, 1992 for a review). Subsequently, I found that similar approaches, known as *microsimulation* models, have been used in the social sciences, e.g. economics, demography anthropology and sociology (Kunstadter *et al.*, 1963; e.g. Orcutt *et al.*, 1961; for review see van Imhoff and Post, 1998; Wachter *et al.*, 1978).

A landscape under swidden cultivation<sup>1</sup> of the Kantu' community (Dove, 1985b) in Kalimantan was selected as the case study to apply this approach. This type of landscape was chosen because it is a relatively simple system where the households' decisions directly alter the landscape. It is also an example where resource management is closely linked to the social system. Labour and land are the main resources in swidden agriculture systems. The magnitude of labour for cultivation is determined by the structure and composition of households, which is in turn related to the prevailing social customs which control how individuals are organised into households (*via* marriage, adoption, etc.). The land tenure system regulates access to land including the distribution of land across generations through rules of inheritance. Swidden systems have also been extensively studied by anthropologists, and there are detailed accounts of the socio-cultural and economic aspects of these systems.

### 1.3 An overview of models

This section is not intended to provide a comprehensive review of land-use models, rather, it describes selected models to show the existing approaches for simulating processes that later become the focus of this study.

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<sup>1</sup> Swidden cultivation or 'shifting cultivation' is an agricultural system characterised by cultivating a patch of cleared forest for one or two years, followed by long period of fallow, before returning to the same patch to repeat the cycle (Spencer, 1966). Throughout this thesis, the term 'swidden cultivation' is used interchangeably with 'swidden agriculture'. In addition, the term 'swidden' is also used to describe an 'active field', as opposed to a 'fallow' plot.

### **1.3.1 Statistical/empirical models**

As mentioned previously, statistical/empirical models have been used to elucidate the major socio-economic and spatial factors that explain the observed patterns of land-use change. Often, they are used to confirm widely held views, e.g. that population growth is related to deforestation or that increasing access also increases the rate of deforestation. Below are examples of such studies.

Southgate *et al.* (1991) used regression analysis to study the inter-relationship between land clearing, rural population growth, local demand for agricultural commodities, infrastructure development and tenure insecurity in expanding agricultural frontiers in Ecuador. This study showed a positive correlation between agricultural colonisation and the size of nearby urban populations, soil quality and road access to the area. The study found that deforestation occurred as a consequence of demographic pressure brought about by agricultural colonisation and the colonists' attempt to safeguard their legal hold on frontier land.

Results from a regression model developed by Ludeke (1990) for tropical forest in Honduras revealed that proximity to the forested/deforested edge, proximity to roads and proximity to house/shelter were strongly related to deforestation. Similar conclusions with regard to the importance of road access have also been reported in the Philippines (Liu *et al.*, 1993) and in Cameroon (Mertens and Lambin, 1997). Both of the above studies identified the degree of fragmentation as another important factor related to deforestation. In fragmented areas, forest patches are small, which means that there is more edge per forest patch exposed to human activity. Consequently, small patches of forest are easier to clear compared with large forest patches (Liu *et al.*, 1993).

### **1.3.2 Dynamic simulation models**

Wilkie and Finn (1988) developed a simulation model to investigate the long-term effects of swidden cultivation on forest composition and landscape structure in the Ituri forest of northeastern Zaire. Their model simulates two main processes, swidden (field) selection and forest succession. Forest succession is simulated as a function of the age of vegetation, duration of adjacency with climax vegetation and

presence of rootstock. Factors to be considered for swidden selections included the land tenure system, fallow length as a proxy of soil fertility and travel time. Their study showed that the distribution of forest cover types and the associated spatial pattern of the landscape (number and size of patches) varied predominantly with different population pressures, land tenure systems and rules for minimum fallow length.

A model developed by Thornton and Jones (1998) simulated land-use decisions for a hypothetical agricultural landscape. The landscape consisted of a set of plots where each household can own between one to five plots. Unlike the Wilkie and Finn model, which seemingly dealt with only one type of cultivation and one plot in each year, households in their model also select the type of crop from several possible options for all their plots. The crop options used were beans, maize, pasture and a fallow option. The crop choice was based on (1) the expected gross margin of each land-use, which is calculated from the quantity of product, product price, input cost and location cost, and (2) a household preference for each crop type. In principle, a crop with an above-average gross margin is more preferable. The model also tracked the household wealth using the cumulative gross margin as a proxy. A crop type was selected only if the household had enough wealth to purchase the necessary inputs.

What is interesting in the Thornton-Jones model is the way in which the alternate cropping and fallow was simulated. Fallow was considered as a type of land-use, for which there were no input costs or economic returns. The model simulated the declining fertility, which took into account land quality and nutrient characteristic of the crop. Declining soil fertility resulted in lower yields. In some circumstances, the low crop yields were such that the gross margins of non-fallow land-use were actually lower than that of fallow land-use, which was the criterion used to trigger the decision to fallow the plots. Therefore, the duration of fallow was not enforced by a pre-determined rule but evolved dynamically during the simulation. The simulation results showed that a steady state landscape composition resulted with the fallow and bean land-use dominating the landscape. In terms of spatial configuration, the landscape became less heterogeneous and patches tended to become more clumped through time. Another interesting feature is that irrespective of the initial



land holding distribution, the distributions of household wealth tended toward a skewed distribution where a minority of households held the majority of the wealth.

Dale *et al.* (1993) developed a model simulating the colonisation of a tropical forest in the Brazilian Amazon by farmers. The model simulated the arrival of colonist farmers, the selection of a farm lot (size ranges from 53 to 120 ha), the shifting of farmers to different lots and the emigration of farmers from the region. The lot selection was based on an index which represented the overall attractiveness of the lot, and takes into account the lot size, soil suitability, distance-related factors, carbon level of the soil, vegetation type and length of current lot tenure. The inputs of the model included the probability of tenants leaving the lot, the amount of land cleared and the proportion of land-use of the cleared area (for annual, perennial, fallow and pasture) across the years. As a measure of the ecological impact, the model estimated the carbon released from the vegetation and soil over time.

Their model was used to explore the dynamics of the system under different land-use decision-making formulations. Firstly, they found that varying the factor that is most heavily weighted in the index for lot selection affected the amount of deforestation but had little impact on the amount of carbon released (Dale *et al.*, 1993). The second simulation experiment ran the model under different land management scenarios (worst case, typical case and best case), which differed mainly with respect to the amount of land cleared by each farmer each year (Dale *et al.*, 1994). The results showed that different land management significantly affected the rate of deforestation and carbon released. The model also estimated the social implications of the different scenarios. In the worst case scenario the regions could support farmers for less than a decade, while in the best case scenario the region could support families for about 40 years. In both simulation experiments, the spatial configuration of the landscape varied over time with the different scenarios.

In the above-mentioned models, the dynamics of the landscape are mostly driven by decisions on 'what to cultivate' and 'where to cultivate'. In that context, Dale *et al.* (1993) and Thornton and Jones (1998) have both shown that simulating the decision-making process can be greatly simplified by using a site index, which summarises the economic and ecological values of a site with respect to a particular land-use.

### 1.3.3 Individual-based forest succession models

The tenet of individual-based modelling is that individual organisms are represented as an entity having a unique characteristic, as opposed to lumping the individuals into groups and assuming that their characteristics can be summarised with a single variable such as population size (Huston *et al.*, 1988). A specific application of an individual-based model, called a 'gap model', simulates the dynamics of forests at a spatial scale of a forest gap of a typical size created when a tree eventually falls over (Urban and Shugart, 1992:252). The first well-known gap model, JABOWA was built by Botkin *et al.* (1972). Since then, numerous derivations of JABOWA have been developed for various forest types; temperate forest (e.g. Shugart and West, 1977; Smith and Urban, 1988), boreal forest (e.g. Bonan, 1989; Prentice and Leemans, 1990), montane eucalypt (e.g. Shugart and Noble, 1981), sub-tropical rainforest (e.g. Shugart *et al.*, 1980) and tropical rain forest (e.g. Doyle, 1981; Kurpick *et al.*, 1997).

Each gap model varies slightly in the level of detail at which various processes are simulated, but they still all share a common set of assumptions and underlying logic (Urban and Shugart, 1992). In all gap models, the establishment, growth and mortality are simulated for individual trees. The structure and composition of the forest over time is determined by the competitive interactions between the trees. The competition between the trees is explicit but indirect. This means that each tree modifies the plot-level resources (e.g. light through the shading from the leaves); these aggregate resources act as environmental constraints that reduce the potential annual growth increment expected for a tree of a given size and species (Urban and Shugart, 1992). The plot-level resources act as an environmental filter (Harper, 1977) and determine which species establish. Mortality is usually a function of the age of the tree but is increased for an individual tree that is suppressed and growing slowly or damaged by a simulated disturbance.

### 1.3.4 Microsimulation models of human populations

Microsimulation models take a similar approach to the individual-based modelling of trees, where the dynamics of human population are simulated as a function of demographic events occurring at a person level (e.g. birth, marriage and death). Age- and sex-specific demographic rates are generally the main inputs for simulating population dynamics. In some models, individual persons are organised into households using a set of assumptions on societal preferences for residence. The history of individual persons as well as households can be followed, which enables events to be simulated as a function of either the 'state' of a person (e.g. age, marital status, and employment) or a household (e.g. wealth). If necessary, interaction between individuals could also be readily simulated, using the same basic approach to simulate the interaction between trees in gap models. Another common feature of microsimulation models is that the links to the biological father and mother are conserved and this enables kinship to be tracked at any time.

Some microsimulation models are purely demographic models. However, in many others, the demographic component is only a part of larger model also containing socio-economic components. Ridley and Sheps (1966) developed a purely demographic model called REPSIM to study the relative importance of various demographic and biological factors on natality. Another demographic model is POPSIM developed by Horvitz *et al.* (1971, cited by Rao *et al.*, 1974). The POPSIM model was later used by Rao *et al.* (1974) to analyse the outcome of alternative family planning programs. Hammel *et al.* (1976) developed SOCSIM, which is a demographic model that simulates the formation of households. SOCSIM was applied to study the patterns of household structure under different rules for living arrangements in pre-Industrial English villages (Hammel and Wachter, 1977; Wachter *et al.*, 1978). Smith (1987) used a microsimulation approach to study kinship. Among the first microsimulation models developed for policy analysis is DYNASIM developed by Orcutt *et al.* (1976). This model simulates a sample representation of the United States population and relates the behaviour of the microeconomic unit (i.e. families) with macroeconomic conditions. In a similar application, Nelissen (1995) developed and used the NEDYMAS model to analyse the re-distributive impact of social security schemes in the Netherlands.

In the field of human ecology, Weinstein *et al.* (1983) developed the NUNOA model, which was applied to a hypothetical farming and herding community of Quechua Indians in the high Andes. This model simulated the annual energy balance of individuals, families and extended families. The model tracked the energy consumed as well as spent in farming and herding activities. In this model, births, deaths and marriages were linked to the energy balance of the family; for example, the probability of giving birth was reduced when the family experienced an energy deficit. Crop plantings and livestock production were included, but not in a spatially explicit form. To my knowledge, the NUNOA model appears to be the first simulation model that explicitly couples demographic processes, land-use activities and environmental conditions. Recently, a model with similar approach was developed by An *et al.* (2001), which simulated the impacts of the use of fuelwood by households on panda habitat.

#### **1.4 The Kantu' of West Kalimantan as a case study**

The Kantu' community was selected as a case study because there was extensive existing anthropological data gathered by Michael R. Dove. Dove intensively studied one longhouse community at Tikul Batu for more than two years (1974-1976). This study site was geographically located near the intersection between the Empanang and Kantu' rivers in the Kapuas Hulu regency of West Kalimantan province (see Figure 1.1). The data used to construct the model developed in this thesis is mostly derived from Dove's subsequent reports (Dove, 1980; 1981; 1983; 1984; 1985a, 1985b; 1993). The data were supplemented by a brief field visit to Dove's study site in November 1999. This study also benefits from the availability of ethnographic data for other similar communities in the Kalimantan/Borneo region, and particularly many groups who belong to the Ibanic ethnic complex with whom the Kantu' share many common socio-cultural elements (Wadley, 1997a). These groups include the Iban of Sarawak (Freeman, 1992; and Padoch, 1982), the Mualang (Drake, 1982) and the Iban of Batang Lupar, West Kalimantan (Wadley, 1997a). These reports have been used for the purpose of model construction when there is no comparable account for the Kantu'. Throughout this thesis I make the assumption that the socio-cultural system of the Kantu' is similar to that of the Iban and Mualang.

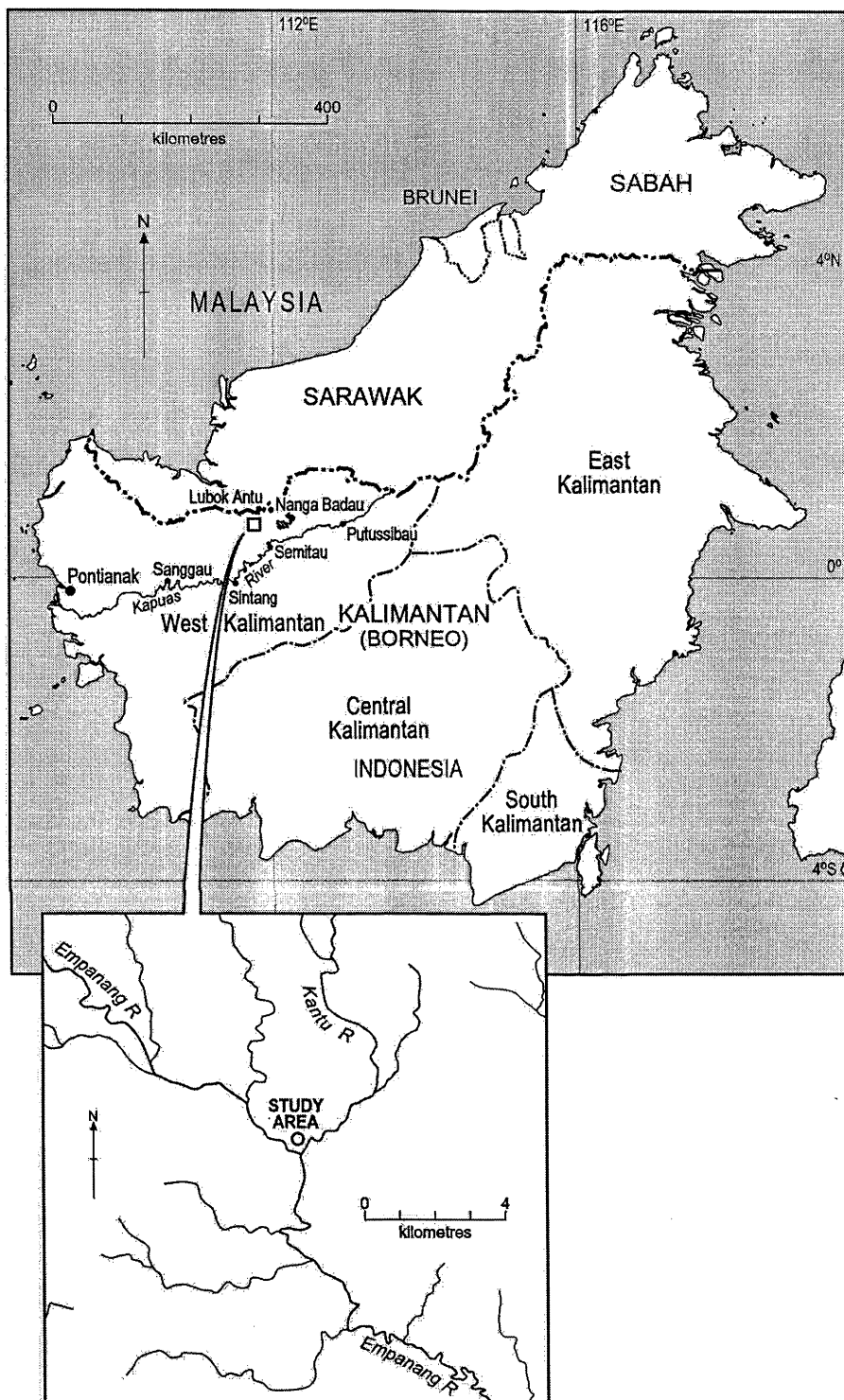


Figure 1.1 Study area is located in Kalimantan, which is the Indonesian part of Borneo island. It administratively belongs to the Kapuas Hulu regency of the West Kalimantan province.

Detailed accounts about the Kantu', its socio-cultural and land-use practices are presented in Chapters 2 and 3 of this thesis. Here, it is sufficient to mention that during the time of Dove's study, the Kantu' lived a largely subsistence economy in which the swidden cultivation of rice (often mixed with maize, cassava or vegetables) was the main subsistence activity. They also engaged in several non-subsistence activities to earn cash for buying basic tradeable goods such as salt, tobacco, cooking oil, kerosene and clothes. The cash-earning activities included working for wages in nearby Sarawak, growing pepper crop, trading and tapping rubber. Nevertheless, tapping rubber is the primary source of cash for the Kantu'. Income from rubber is also crucial as a 'cushion' in the event of economic misfortune, particularly following the failure of harvests, when it becomes necessary to purchase additional rice. Despite engaging in some form of market-oriented activities, Dove (1981,1985b) suggested that swidden cultivation was the central economic activity of the Kantu'.

Many changes have occurred in Kantu' society since the time of Dove's study 25 years ago. The longhouse Tikul Batu was demolished in 1980s after diarrhea epidemics killed many people. The residents of the longhouse were relocated to an area nearby and have lived in detached houses since then. The study area used to be isolated and river travel used to be the only way to reach the area. The access to the area has been greatly improved following the construction of a road connecting the area with Lubok Antu town in Sarawak in early 1992 (Wadley, 1998). A surge in pepper prices, mostly since 1997 represents another significant change in economic circumstances (KOMPAS, 1998, 1999). That increase combined with the good market access in Lubok Antu town has triggered a renewed interest in growing pepper. In summary, the Kantu' are now more involved in the market economy than they were 25 years ago.

Despite those recent changes, during my field visit, I observed that many aspects of the Kantu' life of relevance to this study have remained largely unchanged. The Kantu' still cultivate rice in swiddens for consumption, although the harvest often only lasts for a couple of months. The swidden cultivation technique is largely the same except the use of herbicide has replaced backbreaking hand weeding. Rubber remains a source of cash, although other money earning activities (e.g. working for

wages in Serawak and growing pepper) have become more important. The household is also still the main unit of production, consumption and property holding and the social rules regarding land inheritance are more or less unchanged.

### 1.5 The modelling approach adopted in this study

The central aim of the model constructed in this study is to simulate the land-use decisions made by individual households and to simulate the consequences of those decisions on both the landscape and the economic welfare of the community. Although there have been some socio-economic changes (described above), the model as presented in this thesis is more or less based on the situation as described by Michael Dove twenty-five years ago. The main reason for making this *apriori* decision was to simplify the model representation. Combining the microsimulation/individual-based and land-use model is still a pioneering work. In this regard, that taking a simple case is the best way to start. I believe that this decision is appropriate given that the primary objective of this study is to establish a framework for linking the demographic, social-cultural, economic and ecological factors affecting landscape dynamics in a spatially explicit way. Therefore, the main driving force affecting the dynamics of the system in the model described in this thesis is population growth. Nevertheless, a simple form of exogenous driving force is also considered.

In simulating the processes, the model uses a *rule-based* approach as opposed to *mathematical* or *statistical* approach in the sense that processes are simulated by a set of rules that are represented as a series of IF-THEN-ELSE statements. These rules represent assumptions about the way that the system operates. They are forms of simplification of otherwise very complex real-life phenomena. Some of <sup>the</sup> rules in the model are adopted directly from existing socio-cultural practices such as incest taboo, inheritance or post-marital residence. Although Dove's work provides a detail account about the Kantu', not all of the information required for model construction was available. In those situations, assumptions were made and have been represented in a transparent way (Wachter *et al.*, 1978).

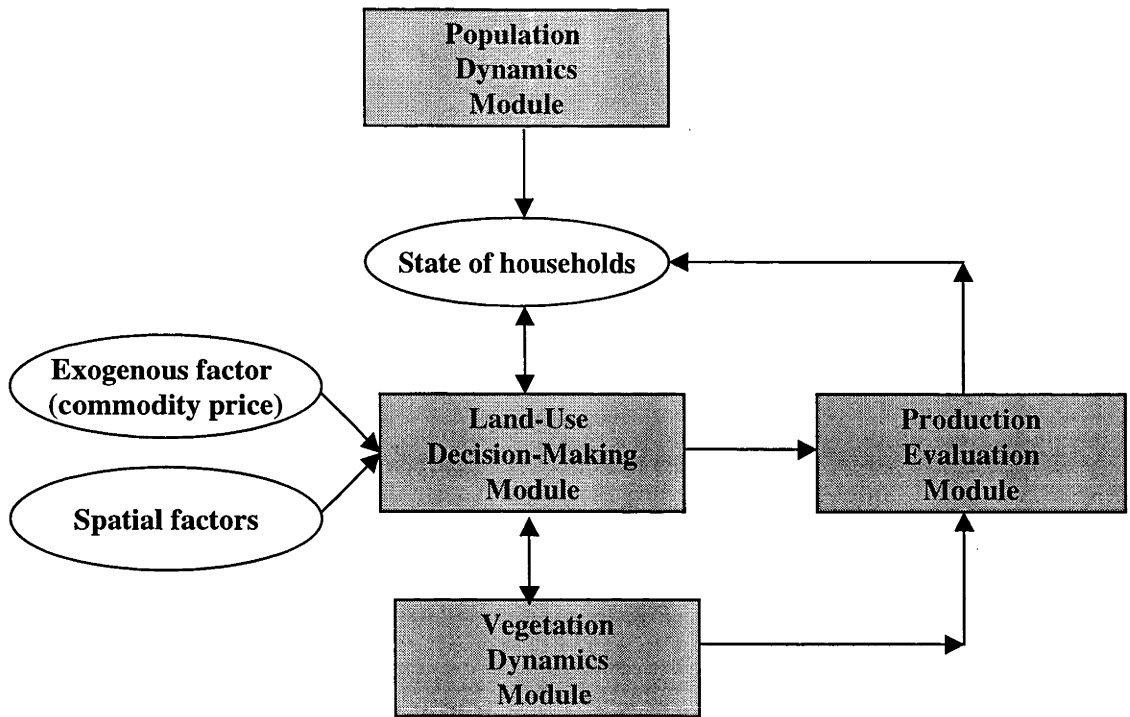


Figure 1.2 The framework of the model (see text of explanation).

The model is organised into four main modules (Figure 1.2) describing population dynamics, land-use decision-making, production evaluation, and vegetation dynamics.

The population dynamics component of this model can be run independently from the other modules and it is frequently referred to as the population model. This module simulates the development of a community by ‘creating’ persons and putting them into households. The formation of households is simulated by applying a set of rules that ‘regulate’ the residence of each individual based on their ‘household membership status’.

The land-use decision-making module takes the household data simulated in the population model as input. The central assumption in this module is that the level of agriculture production is geared to fulfil the ‘subsistence demand’ of the household and labour is mainly supplied by adult members of each household. The land-use decision-making module simulates swidden selection and the execution of various



cultivation tasks (e.g. slashing, felling and harvesting). Site selection for swiddens is made using a site index that takes into account vegetation, ownership and spatial factors (distance and topography).

The production evaluation module is used to determine whether the household's demand for rice in the current year is met by the available production. Rubber production is also simulated in this module, and is mostly a function of the labour available for this activity (after cultivation tasks are completed), the demand for cash used to buy basic tradeable goods, and for the additional cash needed to purchase rice if there is a deficit.

The vegetation dynamics module simulates the successional changes following the abandonment of swiddens, maturation of rubber gardens and rice production. While the model as a whole uses an annual time step, the execution of cultivation tasks uses a daily time step.

I wrote the computer program of the model in Borland DELPHI (Borland-International, 1997). For the 'default' simulation setting (see Chapter 2 and Chapter 5), execution of the land-use model for 75 years took approximately 2 minutes on PC Pentium II with 128 MB RAM. But, when the model is run for population dynamics only, it took less than one minute.

## **1.6 Thesis organisation**

This thesis is organised into five main chapters. The development of the population model is described in Chapter 2. The development of the other three modules that together with the population module constitute the entire land-use model is described in Chapter 3. The land-use model as described in this chapter is referred as the 'default mode'. Throughout this thesis, several types of 'modified modes' are also presented to facilitate explanation for specific phenomena or as part of simulation experiments. Simulation results which are used to analyse the swidden cultivation system of the Kantu' under increasing population pressure are presented in Chapter 4. This chapter also discussed the implications of land-use decisions on both the landscape, and on the economic welfare of the community. Chapter 5 discusses the

sensitivity analysis of the model. This chapter presents simulation experiments where the parameters as well as the rules (or assumptions) are varied. Chapter 6 discusses the model validation and summarises the major findings, strengths and weaknesses of this modelling approach as well as future work.

All appendices are presented in electronic formats on the CD attached to this thesis. The executable program or user interface is presented in Appendix I. Appendix II contains the documentation of main procedures and functions for simulating the model. The complete computer coding of program is presented in Appendix III. Finally, Appendix IV presents the electronic copy of this thesis.

# Chapter 2

## The Population Model

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### 2.1 Introduction

This chapter outlines the development of the population model. The objective of the population model is to simulate the development of a community with characteristics closely resembling those of the Kantu' community. The model simulates the birth, death and marriage of individual persons and, more importantly, household dynamics including the formation and dissolution of households. The most distinct feature of this exercise is the extensive attempt to incorporate socio-cultural aspects into the model. Essential features of Kantu' life which are relevant to the demographic processes are examined first. These accounts are then used as a basis to develop 'rules' for simulating the population dynamics, which are presented in the next section. The discussion on the modelling approach also highlights the complexity of simulating the household dynamics in a stochastic fashion. The behaviour of the model is then explored. To evaluate the model's performance, selected characteristics of the simulated population are compared with those of some 'real' population. In the final section, a summary of the model's performance and some lessons drawn from the process of constructing the model are presented.

### 2.2 Ethnographic background of the Kantu' I: general socio-cultural practices

As with other indigenous groups in the hinterland of Borneo, the Kantu' traditionally live in longhouses. A longhouse is a residential building that consists of apartments (*bilek*), each of which is occupied by a household. A longhouse and a household or *bilek* represent the major social organisations for the Kantu'. Each longhouse has a defined territory within which all resident households are entitled to make a claim to land and thus exclude non-resident households. The Kantu' longhouse of Tikul Batu has a territory of approximately 10 km<sup>2</sup>. The longhouse was first occupied in 1957 by nine households, but there is no information on the population size of this pioneering community. At the time of Dove's study in 1976, there were 123 people

distributed in 16 households, thus the mean household size was about 8, which is relatively large compared with other communities (Table 2.1).

Table 2.1 Distribution of household size in several Borneo communities

Source	Number of members													#HH	Mean Size
	2	3	4	5	6	7	8	9	10	11	12	13	14		
Freeman (1992:10)	0	7	3	4	3	2	2	1	3	0	0	0	0	25	5.6
Freeman (1992:10)	3	2	7	4	9	4	0	0	3	0	0	0	0	32	5.4
Freeman (1992:10)	2	4	9	9	6	7	7	1	3	0	1	1	0	50	6.0
Drake (1982:80)	1	1	1	2	6	5	2	0	2	0	0	0	0	20	6.3
Wadley (1997a:66)	1	1	3	3	2	0	2	2	0	0	0	0	0	14	5.6
Dove (pers.comm)	1	2	0	1	0	3	3	2	1	2	0	0	1	16	7.6

A household is the smallest unit of production, consumption and land appropriation (Dove, 1985b:14-16). As a unit of production, each household cultivates its own swidden. Foods are prepared by each household and shared by all members of the household. Households acquire land by felling and making a swidden in a primary forest. Since family labour is the chief economic resource for the Kantu’ or swidden community in general, the size and composition of the household is a crucial factor in determining household survival. Therefore, demographic processes whereby households increase or decrease in size over time will also be of economic importance.

The size and composition of household changes over time as the household goes through the developmental cycle (Fortes, 1971:4-5). Following the formation, the size of a household increase as children are born and new members are recruited through adoptions or in-marriages. Along the way, the household size decreases with the departure of members due to deaths, migrations and out-marriages. In the Kantu’ and other Ibanic groups, as children reach maturity and marry, they eventually leave the household, but at least one child stays permanently with the parents as the ‘heir’ of the household. Dove (1985b:16) indicated that the heir is usually the youngest child: “Since elder siblings marry before younger ones as a norm, it is they who will leave a parent household through partition or out-marriage, eventually leaving just the youngest of the sibling set in the household ..”. Upon the death of the parent, the heir and his/her spouse and children succeed to the household. In this way, the

existence of the household as a unit is perpetuated from one generation to the next (Dove, 1985b:16; Freeman, 1971:24).

In principle, members of a household are recruited through birth, adoption and marriage (Freeman, 1971:24). Each person acquires initial membership in the parents' household by right of birth. By being a member of the household, a person is obliged to work to ensure the household's survival and, at the same time, he/she is granted rights to the property that is held in common. However, as Freeman (1971:27) described it, "these rights are retained as long as the individual remains a resident member". In other words, each person can only belong to one household. Therefore, it follows that when a person leaves the household, because of out-marriage or adoption, he/she will lose the rights in the original household but will enter the rights of the new household. This 'household membership principle' is fundamental, and as will be shown later it has important implications for inheritance of household property.

Marriage marks one important phase in the household developmental cycle. There are no data on the age of marriage for the Kantu', but Dove (1985b:16) mentions that they usually marry in their middle to late teens. According to Wadley's study (1997a:74) on Iban of Batang Lupar, the average age of the first marriage for women is 21.6 years with the range between 14 to 32 years. For men, the average age of marriage is slightly older, 23 years, with the range between 17 to 30. The relatively late age of marriage especially for men is also indicated by Freeman (1992:25). These studies suggest that men married later because they often worked for cash in other regions.

The Kantu' prohibit marriage to the parent's generation and parents' parents' generation. This proscription thus limits a potential spouse to persons in the same generation, with the exception of siblings and first cousins (Dove, 1985b:25). Essentially the same marriage rule was also reported by Wadley (1997a:74); but Freeman (1971:30) asserted that in his study marriage to first cousins was allowed provided they are not from the same household. Marriages occurred among people in the same longhouse (intra-longhouse) and in different longhouses (inter-longhouse).

Freeman (1992:91-92) found that there was generally a strong preference for marrying within the longhouse.

The newlywed couple usually takes up residence in the household of the wife's parent (*uxorilocal*) or the husband's parent (*virilocal*). The Kantu' have no preference over these two types of post-marital residences. The incidence of uxorilocal and virilocal residence was approximately the same for the Kantu' and Iban of Sarawak (Dove, 1985b:16; Freeman, 1992:25), but higher virilocal residence was reported for the Mualang and Iban of West Kalimantan (Drake, 1982; Wadley, 1997b). Since a marriage always entails a loss of a productive member of one of the two households, one might expect that a decision on post-marital residence would depend on the composition of the two households involved. In this regard, Drake (1982:97) asserted that "an only child and a youngest child has a very strong case for refusing to marry out". The prospect of getting a larger share of the household property was also taken into account in the decision and this will be discussed later.

Following the marriage, the rights of the out-marrying person (person who leaves the household) in the original household are forfeited. He/she then becomes a member of the spouse's household and has the same rights and obligations as any other members born in this household. If the out-marrying person has children, the children are 'incorporated' into the spouse's household and acquire the same rights, as do any children that are subsequently born (Freeman, 1992:28). Freeman (1992:25) suggested that, when marriage is terminated by divorce, the out-marrying persons have to go back to and resume membership of the original household. However, when marriage is terminated by death, the fate of the *affinal*<sup>1</sup> widow(er) usually depends on the stage of marriage. If the death occurs at an early stage of marriage where no children have been born, the *affinal* widow(er) may return to the original household. However, when marriage has been well established, especially when there are children, the *affinal* widow(er) has a strong case to remain in the deceased spouse's household (Freeman, 1992 :37-38). In this case, the *affinal* widow(er) retains membership by right of marriage. As a consequence, should this

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<sup>1</sup> Person who is affiliated to a household by marriage.

*affinal* widow(er) remarry and elect to stay in the deceased spouse's household, she/he is entitled to do so (Freeman, 1992:39).

In order to perpetuate the households, each family must have at least one child. Failure to do so will leave the household with no heir, which leads to the household becoming 'extinct', in which case the property of the household will be claimed by kinsmen in other households (Dove, 1985b:19); but this event rarely occurs. The common solution for the childless couple to prevent household extinction is adoption (Freeman, 1992:18-19). Freeman argued that the majority of adoptions are between close kin but with a strong preference for a child of the siblings. In most cases, children (non-adult) are adopted. In accordance with the household membership principle, the adoptee will lose rights in biological parent's household but acquires rights in the adopted parental household.

The next important phase in the household developmental cycle is household partition, which is the main avenue for proliferation of households. After a period of post-marital residence in the parent's household, all in-marrying children, except the youngest child, eventually move out to establish their own households by a process called 'partition' (Dove, 1985b:16; Freeman, 1992:41-44). In most cases, partition is initiated by the presence of two married siblings. Differences in interest between these two elementary families often fuel tension and eventually lead to departure of one of them, usually the earlier married sibling. The cohabitation between two married siblings is always temporary. Freeman (1992:11) found no single instance of married siblings possessing adult children who still stayed together in the same household.

The occasion of partition is followed by division of the household property or inheritance (Dove, 1985b:18). Regarding the principle of inheritance, Freeman (1992:30) asserted that "siblings are parceners or coheirs and there is thus no differentiation between sexes or between natural and adopted children". The departure of children due to partition should not be confused with that of out-marriage, in which case the inheritance right is forfeited. In other words, the property of a household is inherited by in-marrying children but not out-marrying children. Given the implication of post-marital residence on the number of siblings eligible for

inheriting a household's property, one might ask whether size of sibling set will influence the post-marital residence decision. By recording the incidences of out-marriage and partition (i.e. once in-marriage) according to the size of sibling set, Freeman (1971:48-50) found an increased tendency toward out-marriage the larger the size of the sibling set. This is because in larger sibling sets, the share of each person is smaller, which provides a strong inducement for out-marriage.

Partition can take place several times depending on the frequency of in-marriage. On each occasion, property of the household is divided between the parent's household and the newly formed child's household on 'a person basis' (Dove, 1985b:18). However, it is not clear whether the 'person' refers to all members or just the sibling set, but it seemingly refers to the eligible sibling set. In other words, apportionment of the property should make provisions for siblings staying in the parent's household. Although Dove (1985b:18) and Freeman (1971:51) implied an equal share among a sibling set, Drake (1982:84) asserted that in his study the apportionment was qualified by the contribution to the property. He also suggested that a larger share was usually allotted for the child staying permanently with the parent. All property held in common is subject to division during household partition. This includes rice and rubber groves, but none of the secondary forest plots (Dove, 1985b:18-19). The rights to re-use secondary forest are 'shared' between the parent and children's households created by one or more partitions. Further discussion on land inheritance is deferred to Chapter 3.

Finally, in terms of the characteristics of the initial population, the history of settlements of swidden agriculture communities in Borneo/Kalimantan is often begun with the occupation of unclaimed territory by a group of pioneering households, who emigrate due to land shortage or tribal war (see Padoch, 1982:15-35). Macfarlane (1976:291) suggested that a demographic characteristic of these migrant groups is mainly young married couples with one or two children, or what he called 'classic settler material'. However, Padoch's (1982:86-87) study does not reveal such a distinct pattern for the Iban of Sarawak, in which she found a preponderance of older people among the pioneers. She partially attributed this to the fact that they tended to migrate in whole households, and often nearly entire longhouses, so that the age structure was not much different from non-migrating



groups. The history of the Kantu' community of Tikul Batu was begun in 1957 by nine households, who were originally from another relatively nearby longhouse (Dove, pers.comm.). There is no other information on the structure and composition of these initial households. However, given the geographical proximity of origin, the age structure would likely have been more similar to Padoch's case than to the 'classic settler material'.

### **2.3 The development of the population model**

The population model is constructed using a *microsimulation* approach with the person and the household as the main unit of representation. Technically, the person and household are data units created dynamically during the simulation which store information about the current state (value) of various attributes and links (*pointers*) to other persons or households (Figure 2.1). Among the important links are those between a person to the parent (mother and father). The child-to-parent link is the basic link that enables the model to follow the genealogy so that the kinship relationship among persons can be identified at any time. For example, first cousins are identified by the virtue of common grandparents. Furthermore, the value of the attributes and the links are updated as a result of demographic processes. The most important advantage of representing persons and households as discrete units is that the socio-cultural aspects, which mostly operate at person and household levels, can be incorporated in a 'straightforward' way.

There are two main elements required to construct the population model. The first one is the probabilities used to decide the fate of individual persons with regard to birth, marriage and death. In this simulation these probabilities were derived from empirical demographic rates, such as age-specific fertility rates. The second element comprises the 'social' rules pertaining to household organisation that regulate how individual persons are organised into households. This element defines implications of the household affiliation particularly in terms of rights to property of the household. These rules are crucial in providing an interface between the population and land-use model, as household is the main unit for land-use decision-making. The 'social' rules were mainly derived from the social practises of the Kantu', as

described in the previous section. The assumptions and approaches used in constructing the model will be described in detail in the following section.

Person	Household
<ul style="list-style-type: none"><li>• Identity number</li><li>• Household affiliation</li><li>• Age</li><li>• Sex</li><li>• Biological father</li><li>• Biological mother</li><li>• Adoptive father</li><li>• Adoptive mother</li><li>• Marital status</li><li>• Spouse</li><li>• Age at first marriage</li><li>• Number of marriages</li><li>• Last marriage duration</li><li>• List of children</li><li>• List of unmarried children</li><li>• Years since last birth</li><li>• Residence type</li></ul>	<ul style="list-style-type: none"><li>• Identity number</li><li>• Head</li><li>• Heir</li><li>• ‘Senior’ household</li><li>• List of ‘junior’ households</li><li>• List of members</li><li>• List of married persons</li><li>• List of owned plots</li><li>• List of cultivated plots</li><li>• List of borrowed plots</li><li>• Rice stock</li><li>• Cash stock</li><li>• Rice debt</li><li>• Cash debt</li></ul>

Figure 2.1 Data structure of person and household; not all attributes of a person and household are shown.

2.3.1 Principles of the household organisation

The dynamics of households is simulated based on certain principles of household organisation, as assumed by the model. Some of these principles are introduced here, but more will be presented in the description of the demographic events. In order to simplify simulating the movement of persons in-and-out of a household, the model applies a set of rules that regulates the residence of each individual based on ‘household membership status’. The model specifies three types of household membership status: ‘head’, ‘heir’ and ‘member’. In this case, the head refers to the idea of ‘pun bilek’ or the foundation of the household (Freeman, 1992:30). Pun bilek signifies the successor of the household or the person who leaves his/her natal household during partition and thus becomes the foundation of a new household. The

head can be male or female. Thereafter, the term 'head' is used to denote pun bilek for the sake of convenience.

'Member' status is assigned to each individual recruited into the household through birth, marriage and adoption. However, this status can later be changed depending on the demographic circumstances of the household. 'Head' position is initially assigned during the formation of a new household and will be transferred to the successor only upon the death of the person. The successor has to be an adult person (age  $\geq 15$  years). The model assumes a 'preference' for the youngest child for the successor but this is subject to the maturity of the youngest child at the time of the head transfer. Given this preference, the youngest of a sibling set is assigned as 'heir'; the timing of this assignment is when she/he 'attempts' to marry. In this model, an attempt to marry can be unsuccessful, that is, when suitable partner is not found. Once assigned, the heir status is retained regardless the result of marriage attempt. A household must have a head but it may have no heir, as when the youngest child has not attempted to marry. There is an occasion where the heir is not assigned to the youngest but to a married child, as discussed further when describing household partition. If the head dies and an heir has not been assigned, the head position will go to another person. A failure to find the appropriate successor following the death of the head will trigger household dissolutions.

Membership status is also used as a basis to make decisions on residence. The model assumes that the 'head' and 'heir' persons will not change residence. It follows that upon marriage (first and remarriage) these persons will always bring the spouse to the household (marry-in). 'Members' can marry-in or marry-out. For a person whose status is a 'member' and who elects to marry-in, staying in the parents' household is temporary. The timing when this person and his/her nuclear family has to leave the parent's household will be discussed in section 2.3.6.

### **2.3.2 General approach for simulating demographic events**

The population model simulates five main demographic events: birth and adoption, marriage, death and household partition. It is a closed model (van Imhoff and Post, 1998) in the sense that a new individual is created by birth only and therefore the

genealogical links are known. In-migration is not simulated in the model to avoid complications associated with the absence of the genealogical history of ‘imported’ persons. The sequence of calls of the simulated demographic events is presented in Figure 2.2. The consequences of one demographic event is simulated for the entire population before moving to the next event. Note that the marriage is simulated after birth and adoption; thus females will not get married and give birth in the same year. Birth, death and marriage are simulated stochastically, but bounded by social rules. Household partition is simulated deterministically. Using the stochastic or Monte Carlo approach, each ‘eligible’ person is assigned a probability of giving birth, getting married and dying. This probability is then compared to a (pseudo) random number generated by the computer. An event is deemed to occur if the random number is less than the probability value.

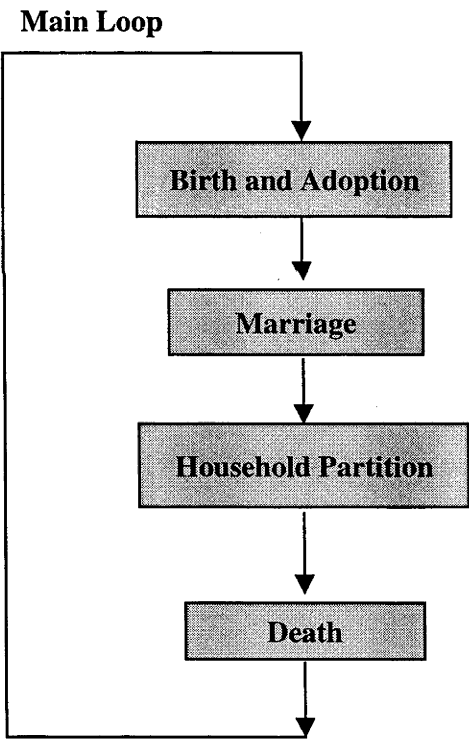


Figure 2.2 Sequence of the calls of demographic events during the simulation.

I applied a simple approach in constructing the probabilities for demographic events by adopting age-and/or sex-based ‘demographic rates’ such as the age-specific fertility and mortality rates. Data on the demographic rates of the Kantu’ are not available. Given this constraint, the strategy was to set up a simulation experiment

that applies several probability distributions to find an ‘appropriate’ probability schedule that results in population characteristics closely resembling those of the study area. For this purpose, three probability distributions for mortality and fertility were selected. The model assumes that the probability distribution for each demographic event is constant throughout the simulation.

### 2.3.3 Birth and Adoption

The probability distribution of birth is derived from the age-specific fertility rates of West Kalimantan province (Central Bureau of Statistics, 1997:37). Data from 1967-1970, 1986-1989 and 1991-1994 are selected to represent three levels of fertility, that is, high, medium and low fertility respectively (Figure 2.3). The total fertility rate<sup>2</sup> (TFR) for high, medium and low fertility is 6.3, 4.7 and 3.6 respectively. In each case, the pattern is similar, that is, a relatively early child bearing period peaking at around age 20.

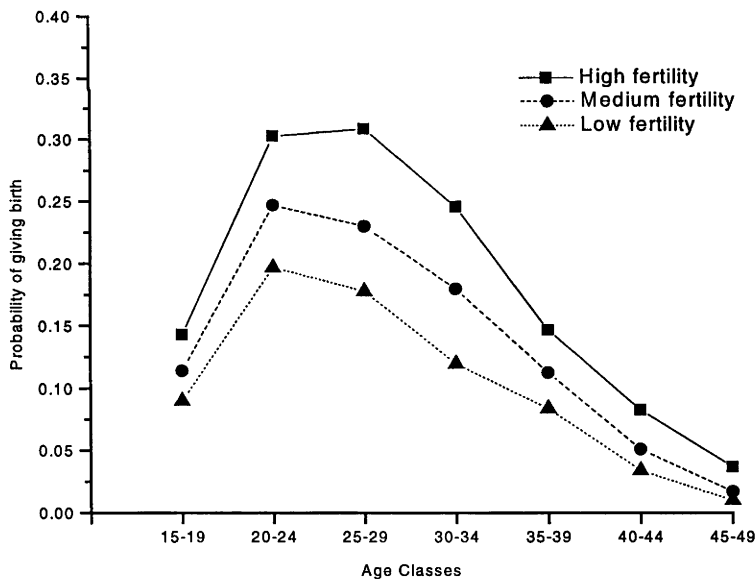


Figure 2.3 Probability distributions of giving birth derived from the age-specific fertility rates of West Kalimantan province (Central Bureau of Statistics, 1997:37). High, medium and low fertility level corresponds to the fertility rates for the period 1967-1970, 1986-1989 and 1991-1994 respectively.

<sup>2</sup> Total fertility rate is the total number of children a woman would have in her life, provided that she survives during the entire reproductive ages (15-49) (Hinde, 1998: 100).

The rules for simulating birth and adoption can be summarised as follows. Birth occurs only within the marital union to a female of reproductive age (15-49). A minimum birth interval of two year is imposed (Central Bureau of Statistics, 1991:33). Once a birth is triggered, a child is created and links are established to the parents. Meanwhile, for married females aged 40 years old or more who have no biological or 'incorporated'<sup>3</sup> children, an adoption is triggered to minimise the chance of household dissolution. The model assumes a preference for a sibling's child (Freeman, 1992:19) as the adoptive child. A sibling will give up a child if he/she has at least one child who remains and if the age of the prospective child is between 5 and 14 (before adulthood). If no eligible sibling's child is found, the search is extended to all other households. The model distinguishes between biological and adoptive parents. Once a child is selected, apart from altering the household affiliation, new links are established to the adoptive parent, while the links to the biological parents are conserved.

#### **2.3.4 Marriage**

The process of marriage involves several steps from deciding to get married, spouse selection and finally deciding on the post-marital residence. Eligible persons for marriage consist of single people or widow(er)s of marriageable age (15-49 for female and 15-64 for male). Polygamy is not allowed. The probability distribution of marriage (Figure 2.4) was constructed from 1980 Indonesian data on the population distribution by age classes and marital status (Jones, 1994:164). The probability distribution of 'first marriage' was derived from the percentage distribution of persons who had ever married. Meanwhile, the percentage of persons who were not in a widowed state was taken as the probability distribution of 'remarriage'. These probabilities were used to determine whether a person in a given age would 'initiate' the marriage process, which can be from the female or male side. For a remarrying person, another rule is imposed to determine the timing of marriage taking into account the duration since the death of the late spouse.

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<sup>3</sup>As a result of marriage with widow who has child(ren).

A marriage will take place only if a spouse can be found; otherwise the marriage is aborted. In the model, the spouse selection is started by compiling a pool of prospective persons, which consists of other persons of marriageable age except those prohibited by the incest taboo. This incest taboo prohibits marriage between persons living in the same household, siblings (including half siblings), first cousins, uncle and niece, and between auntie and nephew. These kinship relationships are tracked through links to the biological parents only. In this model, there is no scoring

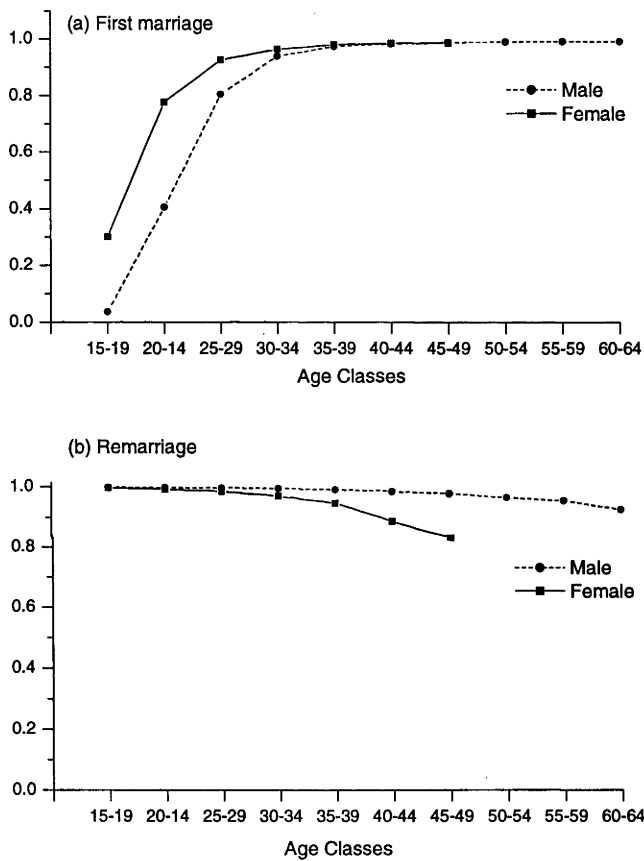


Figure 2.4 Probability distribution of getting married; (a) first marriage, (b) remarriage, which are constructed from 1980 Indonesian data on the pattern of marriages (Jones, 1994:164).

procedure in place to weigh the prospective persons (*cf* Orcutt *et al.*, 1976); the only criterion for choosing the spouse is age difference. The model assumes a preference for older husbands. The desired age difference is determined randomly from a normal distribution with a mean age difference between husband and wife of five years, following median data reported for Indonesia (Casterline *et al.*, 1986:357),

and a standard deviation of three years. Minimum and maximum age difference was also imposed. Men are allowed to marry a person of between 20 years younger and 10 years older and vice versa for women. A random search is carried out to find the first person having the desired age, who is then selected as the spouse. If none is found, a new desired age difference is determined and the process is repeated up to ten times. The marriage process is terminated if no suitable person is found.

The final step in the marriage process is deciding post-marital residence taking into account ‘household membership status’ and the potential inheritors of the household property. The age order of the marrying persons is checked; if the person is the youngest of the sibling set, heir status is assigned. If one of the couple is an heir or a head, he/she brings the spouse into the household. However, if both marrying persons are not eligible to change residence (eg. both are heirs), the marriage is cancelled. Meanwhile, if both of them are simply members of their households, then the decision is based on the number of siblings who are eligible to inherit the household property. The model assumes that the marrying couple will choose to reside in the household with the smaller number of eligible siblings, so that the potential share for each person is larger. The number of eligible siblings consists of the total siblings minus the number of out-marrying siblings. The summary of the post-marital residence rules is presented in Table 2.2.

Table 2.2 Rules for decision on post-marital residence

	F-Head	F-Heir	F-Member
M-Head	Cancelled	Cancelled	F move to M
M-Heir	Cancelled	Cancelled	F move to M
M-Member	M move to F	M move to F	Go to the smaller eligible sibling set

Note: F = female, M = male

Following the decision on residence, the household affiliation of the spouse is altered and the spouse is assigned as a ‘member’ in the new household. In a case of marriage involving persons who have children, the children of the spouse are ‘incorporated’ into the parent’s new household. The incorporated children are thus assigned to a new mother or father, but the links to the biological parents remain unchanged.



According to Freeman (1992:28), the incorporated children have the same status as other children. Consequently, if by any chance, the youngest child is of the incorporated children, this child is entitled to become an heir and in the course of time to succeed to household head. Such a line of succession may be a rare phenomenon, but Freeman (1992:39-40) did documented one such a case, which provides a basis for assuming that a household can be succeeded by a person with no biological link with the previous generation.

### **2.3.5 Death**

To simulate a mortality event, the model adopts mortality rates from model life tables. Model life tables are essential empirical mortality models constructed using a regression approach from the worldwide mortality data. These tables contain a summary of various aspects of the variation of mortality with age (Hinde, 1998:30). There are several sets of model life tables, the particular set used in this study is the regional model life tables constructed by Coale and Demeny (1966). In this set, the model life tables are classified into four groups exhibiting different mortality patterns. These groups are labelled as East, West, South and North, which correspond to the predominant geographical location from which the data in each group were obtained. Each group consists of 25 levels of mortality, each of which sets a life expectation at birth ranging from 20 years to almost 80 years. For countries like Indonesia, where no complete and reliable mortality data are available, the West models are often recommended (Iskandar, 1976:17; United Nations, 1983:13). In this study, the probabilities of dying ( $q_x$ ) from West models level 13, 17 and 21, with the corresponding females and male life expectancy at birth of around 50, 60 and 70, were selected to represent high, medium and low mortality respectively (Figure 2.5). These mortality rates more or less encompass the estimated mortality rates for West Kalimantan, where the life expectancies at birth are 45.9, 50.35 and 62.91 for 1967, 1976 and 1991 respectively (Central Bureau of Statistics, 1997:69).

Despite differing levels of mortality, the shapes of the curves are remarkably similar. In general, the probability of dying for females is slightly lower than that of males. The patterns of mortality show relatively high probabilities of death in infancy. The

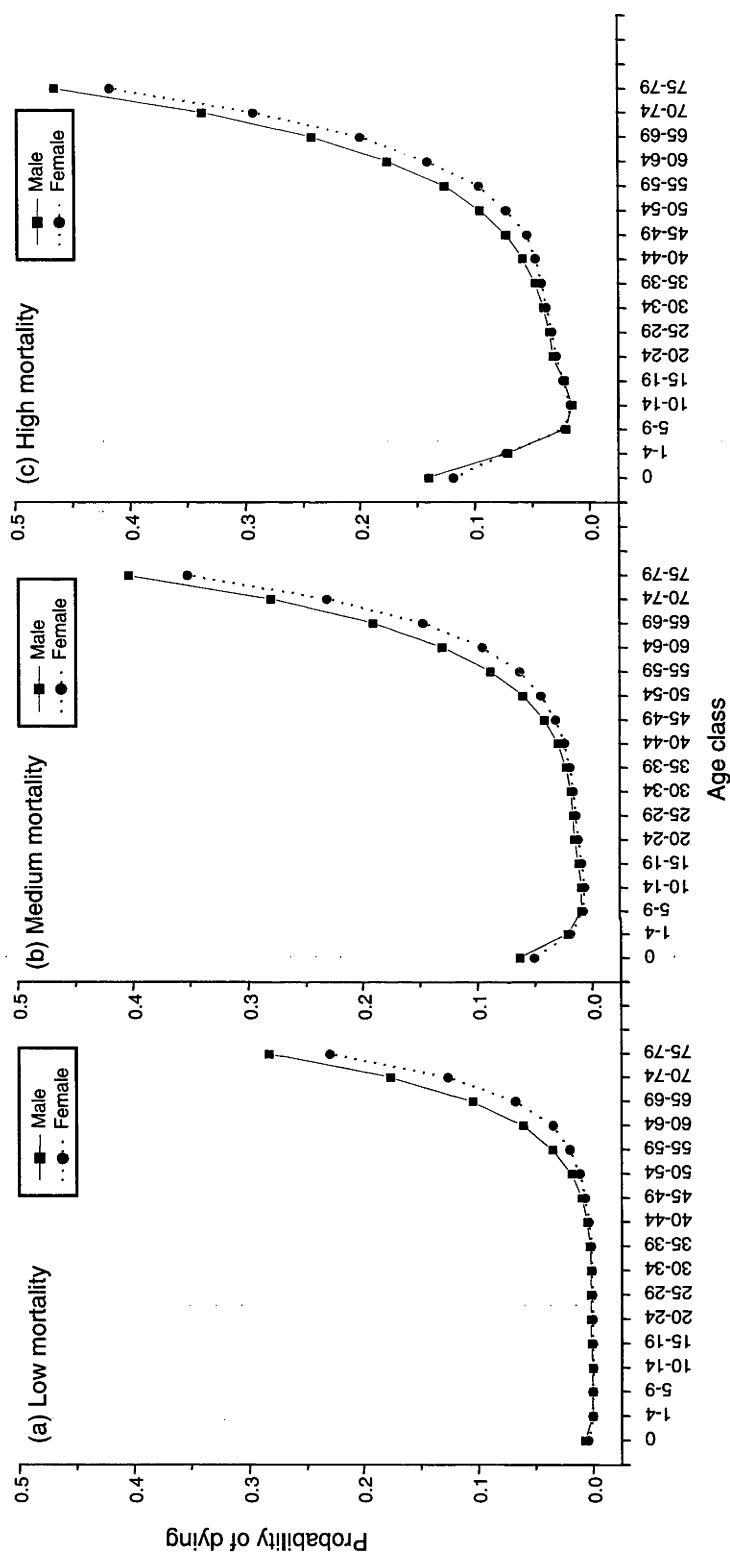


Figure 2.5 Probability distribution of death derived for the regional model life tables (Coale and Demeny, 1966). The 'West' models level 13, 17 and 21 are used to represent the high, medium and low mortality respectively.

probabilities of death decline throughout the childhood and rise slightly from one year to the next until around age 45. After that, the probabilities increase at a higher rate. Comparing the three mortality levels reveals consistently higher probabilities across all ages as the mortality level increases. The difference between the levels is particularly noticeable in the probabilities of death at infancy, in which the value for the high mortality is more than ten times higher than that of the low level. In this model, all persons die by age 80.

In the model, the effect of a death event on the household structure can be complicated. Death can trigger a structural change in a household such as a transfer of the head or heir, adoption or household dissolution. The forms of structural change depends on the 'household membership status' (head, heir or member) of the deceased person (Figure 2.6a-c). The following are further principles of household organisation underlying the rules for structural changes. In principle, unmarried persons always have links to living parents. Consequently, upon the death of the last surviving parent, unmarried children will be adopted by another adult person in the household. Furthermore, the household affiliation of an affine<sup>4</sup> marrying a 'head' or an 'heir' is final; thus, their residence is not changed following the death of the spouse. In this case, the head or heir position is simply transferred to the spouse. However, the household affiliation of an affine whose spouse is a 'member' could be changed following the death of the spouse depending whether they have children or not. If there are children, the affine remains in the deceased spouse's household, otherwise the affine returns and resumes the membership in his/her original household (Freeman, 1992:37-38).

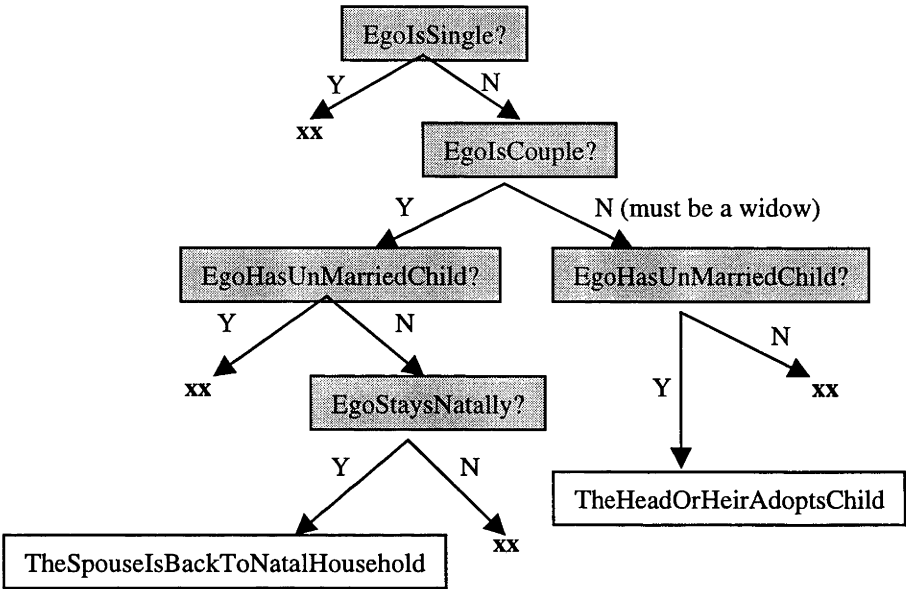
Household dissolution is triggered only when the household's head dies and an eligible person to replace the head cannot be found. When household dissolution occurs, the household property is transferred and divided among the receiving households. The first priority in selecting the receiving households goes to the households of the children of the deceased person. If the deceased person has no married child, the next priority goes to households of the siblings. If no siblings' households are found, three households are randomly selected as the receiving

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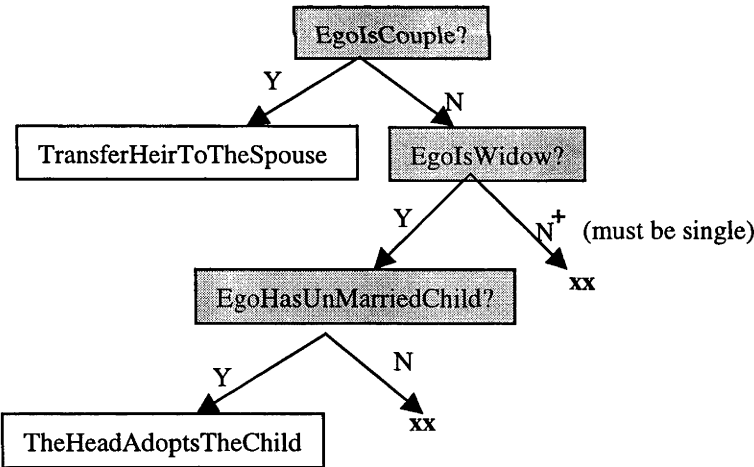
<sup>4</sup> Individuals who had become household members by process of marriage (Freeman, 1992:23)

households. Among the receiving households, one household headed by a married person with a living spouse is selected as the host for the remaining members of the dissolving household.

(a) Death of ‘member’



(b) Death of ‘heir’

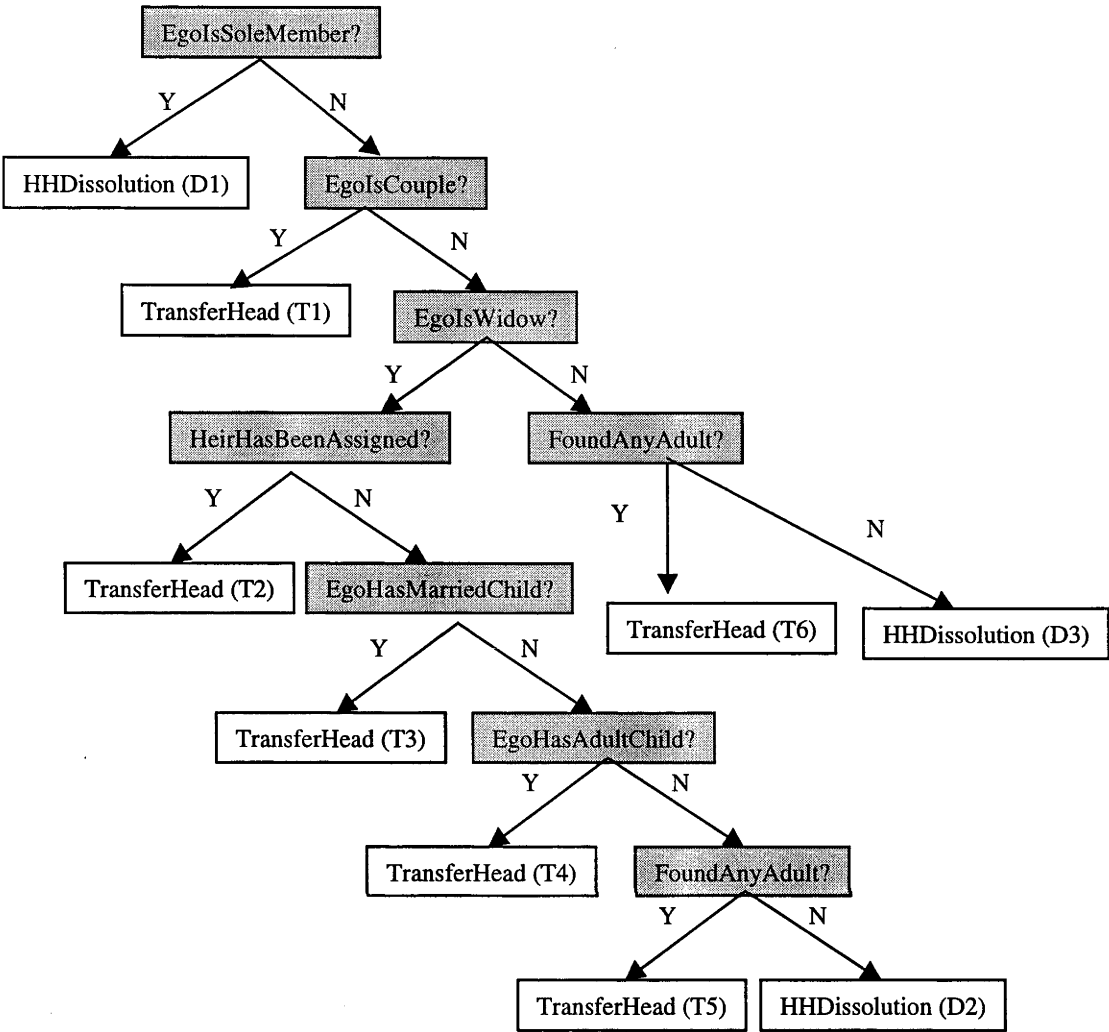


- Notes :**
- Single** refers to a person who never marries
  - Couple** refers to a married person with a living spouse
  - Widow** refers to a married person with a deceased spouse
  - xx** : no major actions
  - +** : a single heir can be found following a failure attempt of the youngest child to find a spouse; the heir status is not aborted despite the failure of marriage attempt.

Figure 2.6 Implications of the death, which are evaluated according to the household membership status of the deceased person (‘ego’).

Continuation of Figure 2.6

(c ) Death of 'head'



The death of a head is particularly important since it is expected to be the timing of the household succession from the parent's to the child's generation. The model specifies six points of transfer for the head position (Figure 2.6-c) based on the demographic circumstances of the household at the time of the death. The transfer to the wife in T1 can be seen as a temporary step before the inter-generation succession occurs. A succession by the heir child (T2) represents the preferred line of succession. Given the timing of the heir assignment<sup>5</sup>, there is a chance that death will occur when an heir has not been assigned, in which case one of the lines of succession T3-T6 will be triggered. In general, giving priority to a married child over others is designed to minimise the future possibility of household dissolution.

<sup>5</sup>The timing of the heir assignment is when the youngest child attempts to marry.

This is based on the assumption that a married child has a higher chance of producing an offspring than an unmarried one, thus the future heir will be ensured sooner. The succession to non-child (T5) could occur, for example, when the deceased head has no adult child but is living with an unmarried sibling. In this case, the sibling takes over the head position and adopts the children. If this person remains single until the time of his/her death, the line of succession T6 will be followed.

### **2.3.6 Household Partition**

Unlike birth, marriage and death events, household partition is simulated in a deterministic manner. Partition is always initiated by the presence of a non-heir but married child. The timing of partition depends on the composition of the household and the summary of the rules is presented in Figure 2.7. In principle, if there is more than one married sibling, the earlier married sibling who has stayed more than five years or has an almost adult child moves out and thus triggers household partition. This rule applies to married persons with or without a living spouse, irrespective of whether there are children or not. Therefore, there could be a chance that a widow with children moves out to create an independent household. Intuitively, such an event might not be realistic; however it is accepted to simplify the model. With these rules, duration of cohabitation between married siblings is generally short, which resembles the situation reported in ethnographic studies (Dove, 1985b:16; Freeman, 1992:11).

Meanwhile, if there is no other married sibling, a married person will stay in the parent's household until the oldest child almost reaches adulthood, after which a partition will take place. Basically, the prolonged stay until another child marries aims to maintain the presence of at least one married child at any time. However, I would expect that, in most cases, the prolonged stay will be precluded by in-marriage of another child. A non-heir but married person with a child almost reaching adulthood will take over the heir position, if the head is a widowed person or a single person but with a low probability of marriage. Again, these rules are imposed to maximise the chance of finding a successor to perpetuate the household; in other words, minimising the chance for household dissolution. Once a partition is

triggered, a new household is created and the departing person is assigned as the head of the new household. In this study, the parents' household and the child's household formed through a partition are called 'senior' and 'junior' households respectively. As household partition can occur several times, a senior household can have a number of junior households. The implications of household partition on the household property division are discussed in Chapter 3.

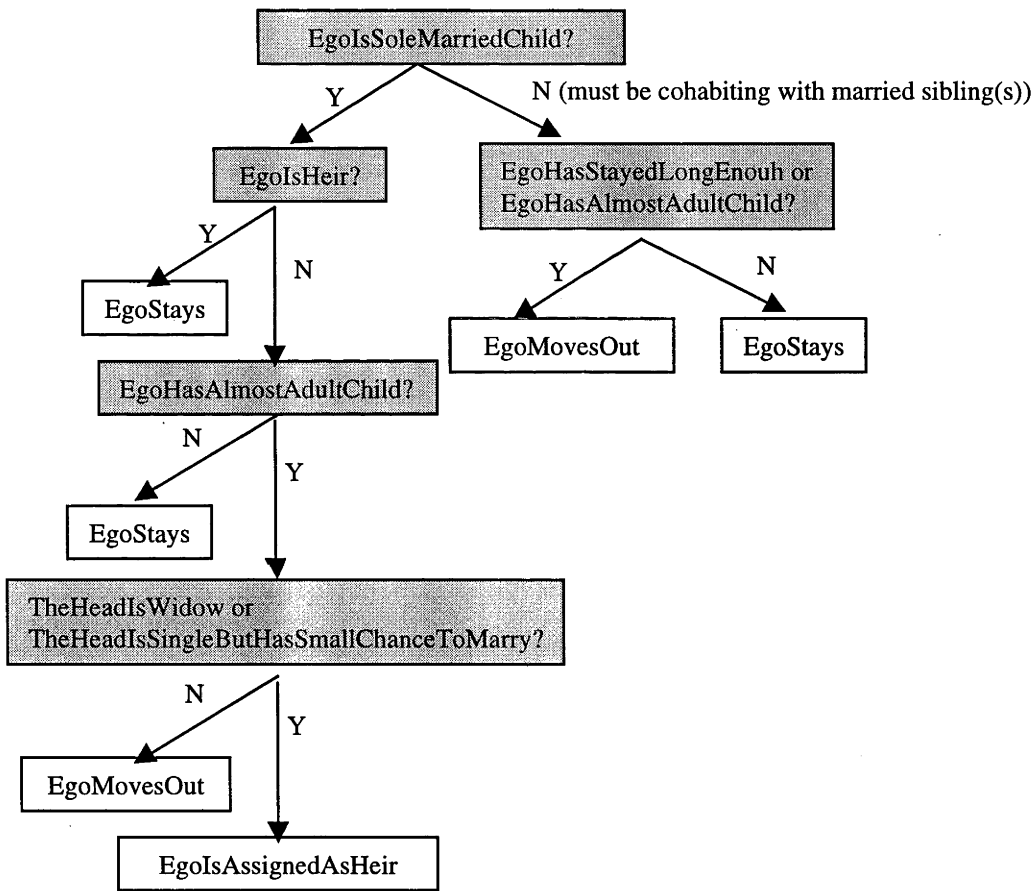


Figure 2.7 Rules for determining the timing of household partition; from the perspective of a married child (ego).

2.3.7 Initial population

To initiate the simulation, the model needs an input of ‘initial population’. The current version of the model requires the user to specify some essential life history attributes of each person including age, sex, marital history, kinship relationships and the household affiliation. If data are available, the initial population can be constructed from the ‘real’ population (e.g. Hammel and Wachter, 1977:119; Howell, 1979:101), so that the life history of each individual is known. With no information available for the Kantu’, the initial population for this simulation was constructed arbitrarily, with the number and life history of persons being assumed but with the same number of households as the pioneering households establishing the Tikul Batu longhouse. Sixty-three persons were assigned to nine households; seven persons to each household. All households consist of a couple with unmarried children or nuclear families, some of whom are at a marriageable age. The range of the couples’ ages was set between 32 – 55 years, partly to represent the presence of older persons, as assumed previously. The age structure for the entire population is presented in Figure 2.8. There is no kinship relationship between these initial couples so that their children can readily inter-marry.

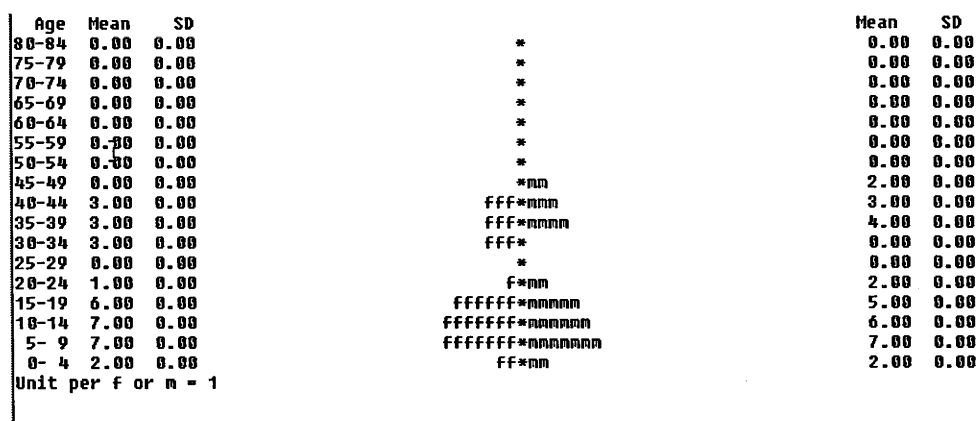


Figure 2.8 Age structure of the initial population (63 persons).



Undoubtedly, there is a degree of subjectivity when the initial population is constructed in the above way. There is another procedure that could reduce some of the subjectivity, which could be implemented in the future. It is first necessary to run a preliminary simulation with a 'dummy' initial population, which is assigned arbitrarily. Once the simulation was run for a sufficient period of time, some households would then be selected, possibly based on an assumed population structure, and they are exported for the input of real simulation. In this manner, the initial households would come from a population whose structure and composition reflects the consequences of the rules and demographic rates used in the simulation. In addition, this procedure would remove some of the subjectivity in assigning the members of initial households and the life history of each person. This suggested initialisation is somewhat similar to that of Wachter (1978:24).

### **2.3.8 Summary of the model development**

To conclude the description of the model, the foregoing discussion has shown the complexity involved in designing a population model using microsimulation approach. The stochastic nature of the simulation necessitates the anticipation of possible circumstances in which demographic events occur. The implications of a demographic event can be simple or complicated depending on the state of a person and the prevailing demographic circumstances in the household. This point is best illustrated by the elaborate set of rules used to determine the implications of death. The range of circumstances that are generated during the simulation could be extensive, some of them not being observed in ethnographic studies. Nevertheless, the model has to deal with every eventuality arising during the simulation. Making assumptions based on best guess is always the last resort when no comparable situations are found from the ethnographic information.

## **2.4 Exploring the behaviour of the model**

Before exploring the behaviour of the model in detail, it is important to emphasise that the model is by no means intended to simulate 'exactly' the population of the study area. The simulated and real population will inherently differ in some respects, of which the following are the most important. Firstly, the model assumes a constant level of fertility and mortality throughout the simulation. This is certainly not the

case for the West Kalimantan province or Indonesia in general. In the last 40 years, Indonesia has been experiencing declining fertility and mortality (Central Bureau of Statistics, 1997:16, 59). A declining fertility rate is also reported for the study area, especially following the introduction of a family planning program in 1978 (Laurensius, pers.comm). Secondly, the model assumes a closed population with no in- and-out migration. In fact, the settlement under study is located adjacent to several settlements where migration between the settlements, driven by marriage or other reasons, does occur. The area also receives an influx of people from other regions coming there as government officers or traders. Likewise, temporary out-migration to work for wages, especially in the neighbouring Malaysian State of Sarawak has also been reported. Technically, these strict assumptions could be relaxed, but this would require a substantial modification beyond the scope of this study.

The following section will present some accounts of the population and household dynamics resulting from the assumptions embedded in the model. The implications of the interaction of various factors affecting population dynamics will be discussed. In addition, a comparison with some empirical data will also be conducted to investigate how far or close the model simulates a certain aspect of the 'reality'. This will allow identification of critical factors causing departure from the reality. When empirical data are available, comparisons will be made against data that specifically reflect swidden agriculture communities in Borneo or the Indonesian population. The focus of comparison is not so much on the exact magnitude but more on the range and plausibility of the trends. The model is stochastic where each simulation that is run under different (pseudo) random stream yields a similar but not identical result. To capture the random variation of the system, the simulation is repeated for 20 replicates (runs) and the results presented in this chapter are the averages from 20 replicates.

#### **2.4.1 Selecting the appropriate demographic rates**

A set of experiments with nine simulation modes combining three fertility and mortality levels were conducted in order to find the combination of rates that produce a population characteristic that closely resembles that of the study area.

Population growth is a simple variable that can be used to indicate population characteristics of the area. Population growth was chosen as a benchmark to select the appropriate fertility and mortality levels. There are no longitudinal population data specifically for the Tikul Batu ‘hamlet’ studied by Dove but such data exist for the ‘village’ where the Tikul Batu administratively belongs. The population size of the Nanga Kantuk village during 1984-1999 is presented in Figure 2.9. During this 16-year period, the mean estimate of annual growth calculated using a regression analysis was 2.9 % with a range of estimate between 2.1 – 3.9 %.

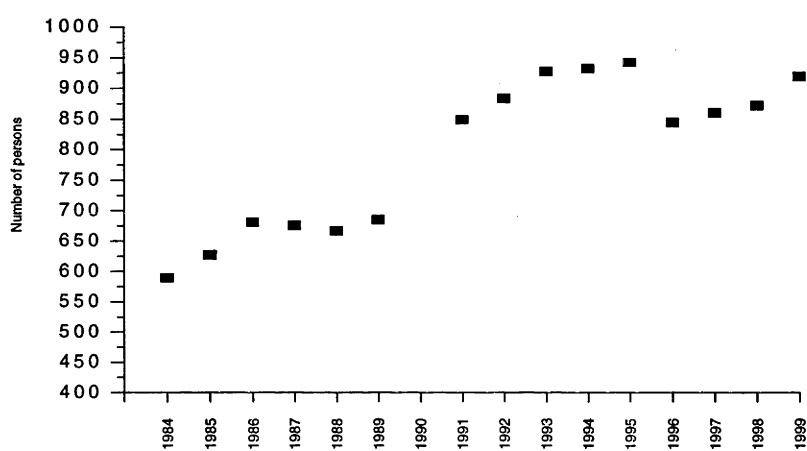


Figure 2.9 Population size of the Nanga Kantuk village during 1984-1999 (field notes, 1999)<sup>6</sup>; data for 1990 was not available.

Table 2.3 Population characteristics of simulated populations with varying fertility and mortality level (mean and standard deviation of 20 replicates).

Simulation Mode	Pop. Size at year 75	Growth Rates (%)	ChildEverBorn*
LFLM	95 (21)	0.1 (0.4)	2.6 (0.6)
LFMM	31 (11)	-2.0 (1.2)	2.5 (0.8)
LFHM	7 (5)	-4.7 (2.5)	2.2 (1.6)
MFLM	193 (36)	1.3 (0.4)	3.7 (0.4)
MFMM	65 (15)	-0.4 (0.4)	3.6 (1.0)
MFHM	15 (9)	-3.3 (1.7)	2.8 (1.7)
<b>HFLM</b>	<b>434 (65)</b>	<b>2.7 (0.2)</b>	<b>5.6 (0.7)</b>
HFMM	142(45)	0.9 (0.6)	4.7 (1.0)
HFHM	28 (11)	-1.9 (1.4)	4.0 (1.9)

Notes :  
 LF, MF, HF: low (TFR = 3.6), medium (TFR = 4.7) and high fertility (TFR = 6.3)  
 LM, MM, HM: low (e<sub>0</sub> = 50), medium (e<sub>0</sub> = 60) and high mortality (e<sub>0</sub>=70)  
 \* Calculated only from the females who survive the entire reproductive period during the last-25 years of the simulation. The children counted include the dead ones.

<sup>6</sup> Data were compiled from unpublished reports from the Sub-District Office of Nanga Empanang.

Meanwhile, the annual growth rates of the simulated population were calculated using an exponential equation<sup>7</sup> for the last 25-years, during which the impact of initial population structure is minimal and the age structure is stabilised. The result (Table 2.3) indicates that the combination of high fertility-low mortality (HFLM mode) produces an annual growth rate that is closest to that of the study area, that is 2.7 %. Given the range of the estimated ‘real’ growth rate and the level of variation among the simulation replicates, this experiment shows that the HFLM mode results in a realistic estimate of the population growth rate.

It should be noted that the mortality probability distribution used in the HFLM mode is based on the assumption that life expectancy at birth ( $e_0$ ) is 70 years, which may be too high for the region. Despite an increasing trend of life expectancy in West Kalimantan, the range of life expectancy is still well below this figure. The estimated life expectancy at birth in West Kalimantan increased from 46 years in 1970s to 63 years in 1990s (Central Bureau of Statistics, 1997:59). The empirical figures should approximate the assumptions underlying medium and high mortality, in which the  $e_0$  is around 50 and 60 respectively. The result indicates that all simulation modes with medium and high mortality result in negative growth rates except in HFMM mode where high fertility can compensate for the loss although the resulting growth rate is far below that of the study area. It is apparent that mortality plays a crucial role in determining the dynamics of simulated population. The processes by which it affects specifically population growth are now briefly examined.

A death event, apart from the direct impact on decreasing the number of persons, also indirectly affects the potential of future population increase. Death of a husband occurring during the wife’s reproductive period breaks the marital union, thus eliminating chances to give birth until remarriage has taken place. In addition, death occurring before adulthood decreases the number of persons entering marital unions and consequently the future number of females eligible to give birth.

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<sup>7</sup>  $P_t = P_0 e^{rt}$ , where  $P_t$ : population size at year  $t$ ;  $P_0$ : population size at initial year;  $t$ : length of the period (years);  $r$ : annual growth rate.

The ‘realised’<sup>8</sup> age distribution at death (Figure 2.10) shows a marked difference among three mortality levels on the death rates during the first four years. High mortality rates in early years of life seems to be the main reason for the impediment of growth in the higher mortality modes because of its effect on decreasing the number of persons surviving to a marriageable age. In addition, the realised number of children ever born is generally lower than the Total Fertility Rate (TFR) of each fertility level, even on the modes with high fertility level (Table 2.3). In summary, given the results of the experiment with nine simulation modes, the high fertility-low mortality (HFLM) mode is accepted as the version that best represents the Kantu’ community. The following sections examine in detail the behaviours of the model run under HFLM.

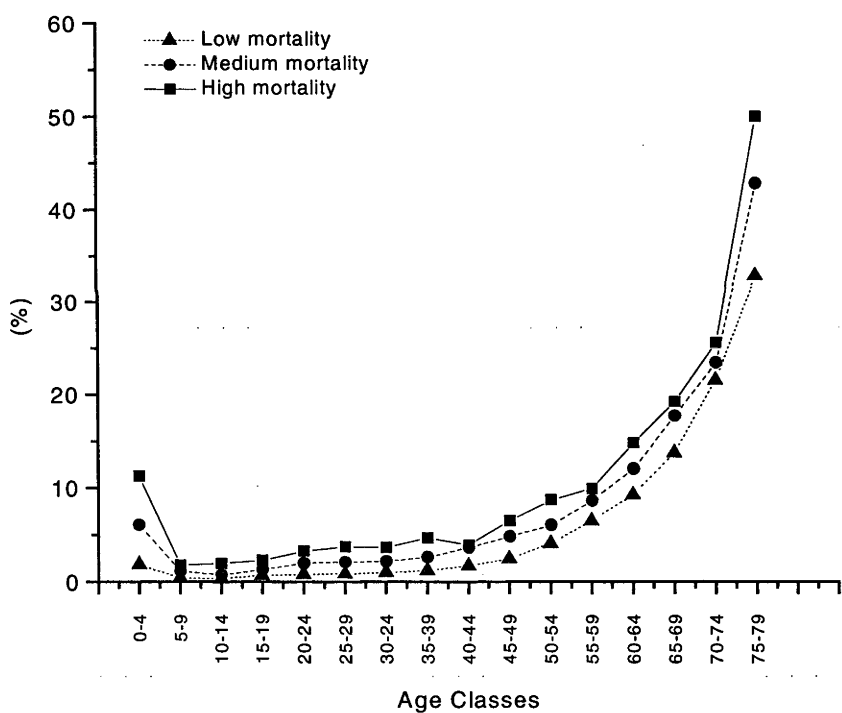


Figure 2.10 Pattern of age distribution at death; from simulation modes with high fertility but varying mortality level. The figure represents the proportion of deaths to the total persons in each age class during the last-25 years of the simulation.

<sup>8</sup> Mortality is simulated solely as a function of age, therefore the ‘realised’ pattern of mortality should be very close to the ‘probability’ distribution, as evidence when Figure 2.10 is compared with Figure 2.5 presented earlier.

## 2.4.2 Trends in marriage and widowhood

For the Iban of Sarawak and Indonesian in general, marriage has traditionally been universal in that all persons have married at least once throughout their life (Freeman, 1992; Jones, 1994:61; Muliakusuma, 1976:1). The Indonesian data presented in Figure 2.11-a indicates an early marriage pattern, which is shown by a sharp decrease in the proportion of single persons during the first-15 years. By aged 30, almost all people have married. Meanwhile, the universal nature of marriage is indicated by the low proportion of single persons in older age classes.

The model produces essentially the same trends with the Indonesian data but with an earlier pattern of (first) marriage, especially for females. While the percentage of 'non-single' women aged 15-19 was 30 % in the Indonesian population, it is 55 % in the simulated population (Figure 2.11-b). Comparison with a single measure of marriage pattern reveals that the simulated mean age at first marriage for females<sup>9</sup> is 16.3 (0.6), while that of Indonesians was 19.3, 20.0 and 21.6 for 1971, 1980 and 1990 respectively (Jones, 1994:80). To explain the reason for such an early marriage pattern, it should be borne in mind that the occurrence of marriage in the model is a function of the probability of marrying and the availability of suitable partners. In such a small population, a lack of partners of suitable age could become a constraint to marriage. However, if this were the case, the result would be that of a late marriage pattern. Therefore, a possible reason for the early marriage pattern is that the value of the probabilities of marrying is too high.

The Indonesian data (Figure 2.11-a) indicates a progressive increase of widowhood at older ages, with a large discrepancy between the proportion of widowed females and males. Seventeen per cent of female aged 45-49 were widowed compared to about 2 % for the males. A preponderance of widow over widower was also reported for the Iban (Freeman, 1992:24-25). Jones (1994:163-164) attributed this discrepancy to a number of reasons. Firstly, the wide age difference between husbands and wives and the slightly higher life expectancy of females; means that women had a higher chance to become widowed than men.

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<sup>9</sup> Age at first marriage for females is particularly crucial since it marks the beginning of 'effective' childbearing period.

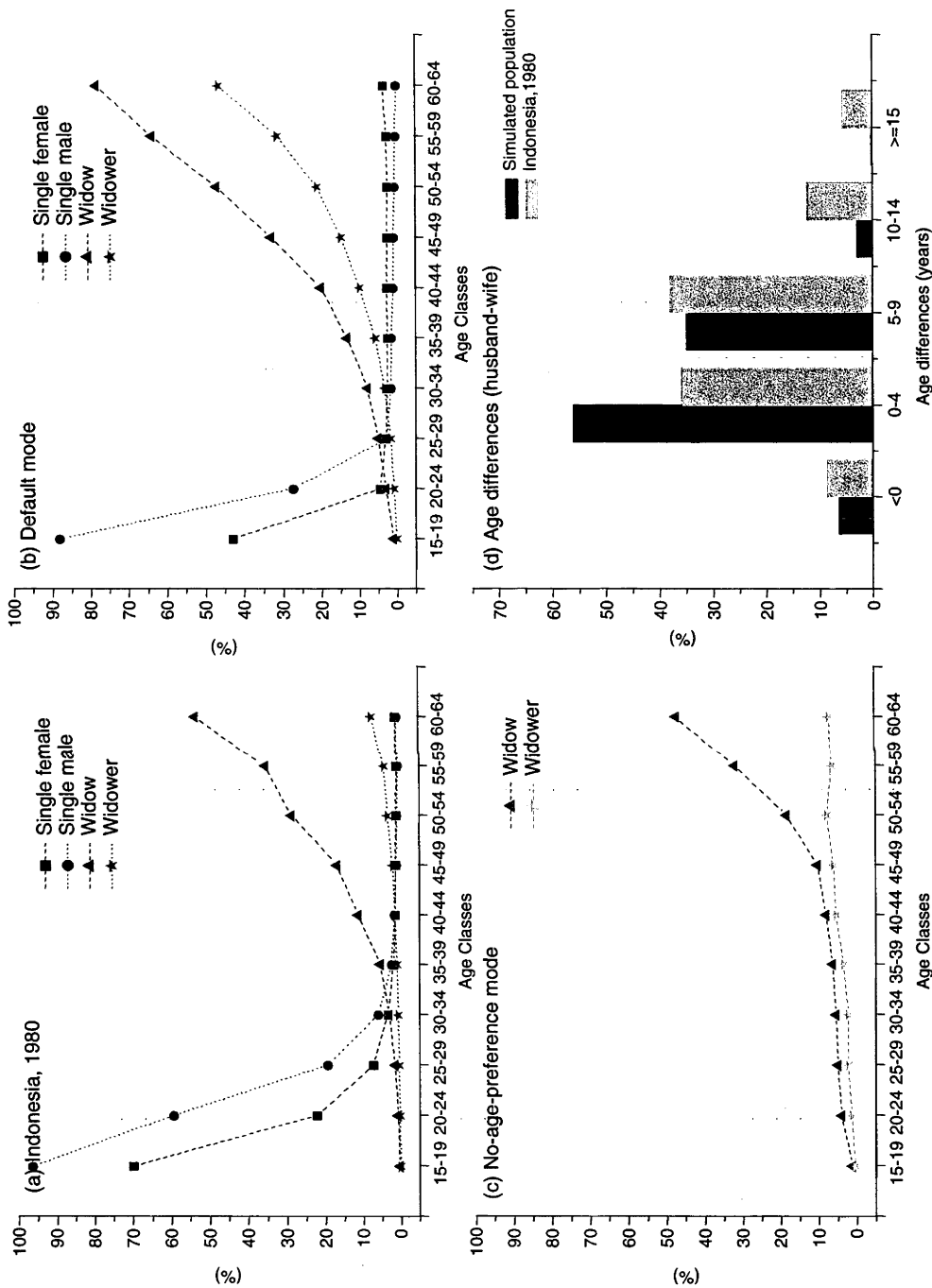


Figure 2.11 a-c: Population distribution by age classes and marital status in (a) Indonesia, 1980 ( Jones , 1994), (b) the simulated population (default), (c) the simulated population with no age preference, (d) Age difference between husbands and wives. The model outputs refer to the situation during the last-25 years of the simulation.

Secondly, there is strong social pressure for widowers to remarry due to a perception that a widowed man is incapable of doing many domestic tasks. Meanwhile, no such pressure exists for women, especially if they have passed reproductive age.

The model also simulates the increasing proportion of widowed persons at older ages; however there is a large discrepancy in relation to the Indonesian population. While only 17 % of women aged 45-49 were widowed in the Indonesian population, the proportion is almost double in the simulated population. A much larger difference can be seen for the men where only 2 % of men aged 45-49 were widowed compared to about 15 % in the simulated population. Since each widow(er) of marriageable age is given a chance to remarry, a high proportion of widows is a sign that realisation of remarriage during the simulation is low. The reason for this is difficulty in finding spouses of a suitable age.

To demonstrate that difficulty in finding suitable spouses is the reason for a low realisation of remarriage, a simulation experiment using a modified version of the model in which the rule for age preference is aborted was carried out. Note that this modification is intended for analytical purposes only to facilitate understanding of a certain aspect of the inner working of the model. In general, the proportion of widowed persons in the 'no-age-preference' mode (Figure 2.11-c) is lower than in the 'default' mode (Figure 2.11-b). This indicates that with no age preference, realisation of remarriage significantly increases. In this case, a continuing supply of potential partners as a new cohort enters marriageable age would ensure a high chance of finding a spouse. The sudden increase in widows aged 50 and older is because marriage for women is confined to age 15-49. This simulation experiment confirms that the impediment to remarriage as seen in the default mode is a shortage of appropriate partners.

One might speculate that the magnitude of the shortage of partners is exaggerated by the 'closed' nature and small size of the simulated population; in reality the pool of potential partners extends beyond the village boundaries. However, any precise statement on this issue can not be made at this stage. One approach that can be suggested to investigate this issue further is to experiment with a larger initial population size.



With regard to the age difference between spouses, the Indonesian data indicate that husbands were generally older than wives (Figure 2.11-d). A tendency of men marrying younger women was also reported for the Iban (Freeman, 1992:24-25). The simulated population in general exhibits a similar pattern with the Indonesian population in that most men marry younger women.

### **2.4.3 The dynamics of households**

From nine initial households, the number of households increases to 78 households as a result of 71 partitions and 2 dissolutions (Table 2.4). The mean size of household at the final year is 5.6 persons/household. This is smaller than the average household size of the Kantu on 1976 (7.6), but it is still within the range of the reported figures for similar communities (5.4-7.6, Table 2.1).

More insights on household dynamics can be revealed by examining the distribution of household size. The distribution of household size approximates a bell shape, which is statistically identical to that of the Borneo communities (Figure 2.13) according to the Kolmogorov-Smirnov two-sample test<sup>10</sup>. In both simulated and real population most households fall between two and nine members per household, i.e. 93 % in the simulated population and 89 % in the real population. The wide range of household size indicates the presence of households at different developmental stages. The small households are mostly newly formed households, while the large ones are likely to be the households that contain married children, and grandchildren, that will soon undergo household partition. The accumulation of large households is precluded by the continuing occurrence of household partition. In this model, the average household size at partition is 8.9 persons with the resulting 'junior' section consisting of 3.6 members and the 'senior' section consisting of 5.2 members. As a comparison, Freeman (1971:43) reported that, for the Iban, the size at partition was

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<sup>10</sup> The Kolmogorov-Smirnov two-sample test is a simple statistical test to measure differences between two distributions, which is based on unsigned differences between the relative cumulative frequency distribution of two samples. Comparison between the expected critical value and the maximum difference between the two cumulative frequency distributions leads to decision whether the distribution for the two samples is identical (Sokal and Rohlf, 1981).

eight or nine members with the ‘senior’ section having five or six and the ‘junior’ section three or four members.

Table 2.4 Selected outputs pertaining to household dynamics

Variables	Mean (SD)
Population size at year 75	434 (65)
Number of households at year 75	78 (12)
Household size at year 75	5.6 (0.4)
Number of marriages	169 (23)
Number of uxorilocal residence	76 (13)
Number of virilocal residence	92 (13)
Number of partitions	71 (12)
Household size at partition	8.9 (0.4)
‘Senior’ household size after partition	5.2 (0.3)
‘Junior’ household size after partition	3.6 (0.2)
Number of adoptions	1.3 (1.7)
Number of dissolution	2.1 (1.7)
Number of dissolution at D1	0.7 (0.8)
Number of dissolution at D2	1.4 (1.3)
Number of dissolution at D3	0.0 (0.0)

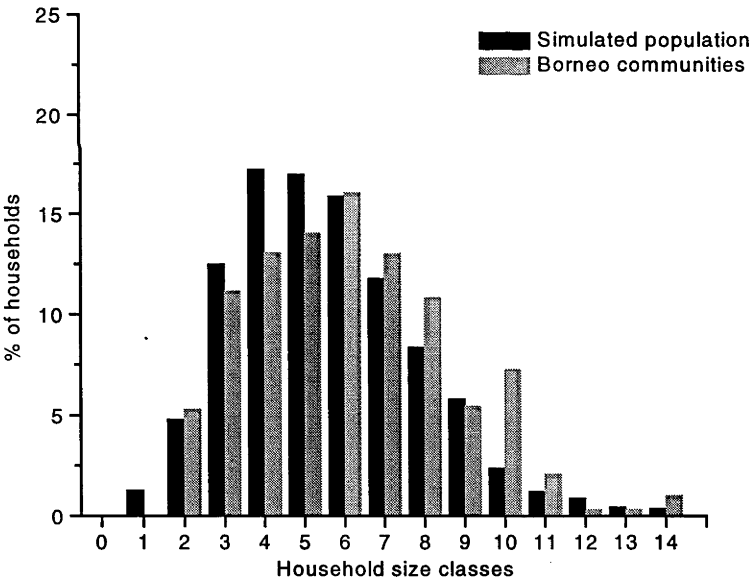


Figure 2.13 Household size distribution of the simulated population at year 75 and the summary of household size distribution of the Borneo communities whose size distribution is presented in Table 2.1. The latter is calculated by averaging the proportion in each size class. These distributions are statistically identical based on the Kolmogorov-Smirnov two-sample test at  $\alpha = 0.01$  with  $n_1$  and  $n_2 = 100$  (total percentage).

With regard to the pattern of post-marital residence, Freeman (1992:25-26) reported 51 % of uxorilocal (at the wife's house) and 49 % of virilocal (at the husband's household) domicile. A similar finding was also reported for the Kantu (Dove, 1985b:16). Freeman used the almost equal incidences of both types to demonstrate that both types of domicile are equally acceptable and neither type receives any sort of special preference. Apart from the sex consideration, Freeman (1971:48-50) also found that size of sibling set correlated to the decision on residence with a tendency toward out-marriage as the size of sibling set grew larger. These two notions are encapsulated into the model in that there is no sex-based preference but the preference is given to the side with a smaller number of eligible siblings. The simulation result shows that of the total 169 marriages, uxorilocal residence occurs in 45 % of cases, leaving 55 % of virilocal residence cases. In other words, it simulates a slightly higher virilocal incidence compared with the empirical data. I was not able to establish the reason for this except that it is due to random variation. The rule of post-marital residence will be modified when the population model is coupled with the land-use model by taking into account the size of land holding.

Another critical aspect of the dynamics is household dissolution, which occurs when no suitable successor is found following the death of the head. In reality, the occurrence of this event is rare (Freeman, 1992:18). Throughout the simulation, the chance of household dissolution is minimised in a number of ways. One is by triggering adoptions for childless couples. Despite the inherently high fertility, the occurrence of adoption in 1.3 cases indicates that few couples fail to produce children. Further examination reveals that all adoption 'attempts' are successful, yet household dissolution still occurs in 2.1 cases, which confirms that infertility is not the reason for household dissolution.

The chance of household dissolution is also minimised by giving priority to a married child to succeed the household (see Figure 2.6-c). In turn, the chance to have at least one married child in residence at any time is maximised by lengthening the stay of a non-heir but married child until another sibling gets married (see section 2.3.6). Despite such anticipations, demographic circumstances leading to household dissolution still emerge, albeit rarely. An examination of the timing of household dissolution reveals that most of them (1.4 cases) occur when widowed persons living

with non-adult child(ren) die, which is specified as point D2 in Figure 2.6-c. Another 0.7 cases happen when the last surviving person is a single (D1) living alone. In general, the marriage constraint due to shortage of suitable partners discussed earlier contributes to the occurrence of household dissolution. This is supported by the fact that when the model is run with no rule on age preference, the frequency of household dissolution drops to an average of 1.2 cases.

## **2.5 Conclusion**

This chapter has outlined the development of the population model for the Kantu. The extent of the ethnographic information available has enabled the distinct features of the community to be depicted in the model. However, due to lack of site-specific data, the demographic rates and structure of the initial community are assumed based on the best available regional or national data. Therefore, the performance of the model was evaluated more on a qualitative than quantitative basis. Selected characteristics of the simulated population have been compared against some real populations. Most importantly, the model is able to represent the magnitude of the population increase in the study area. The model simulates a plausible pattern of marriage but the timing of first marriage could be too early. In addition, the closed nature of the model seems to contribute to the marriage constraint that to some extent leads to a high proportion of widowed persons and subsequent occurrence of household dissolution. A realistic pattern of household proliferation through partition is also exhibited by the model. In general, the trends or patterns of the characteristics of the simulated population are very close to those of the real populations.

Much has been learnt from the process of constructing the model. A particularly challenging task is how to make a trade-off between the need to incorporate sufficient detail of the 'social practices' as suggested from the ethnographic information and to achieve a simple model representation. This is particularly so when the model is constructed using a microsimulation approach. The abstraction of the system in microsimulation is very close to reality, which often creates temptations to include every piece of detailed ethnographic information in the model since this should technically be feasible. A careful consideration has to be made as to whether increasing complexity by adding new features to the model can be justified.

This is because as the complexity increases the task to ensure that the model behaves as expected becomes more difficult. Therefore, it is important to bear in mind that a model should be designed in such a way so that the complexity of the model can be confined to a manageable level.

# **Chapter 3**

## **The Land-Use Model**

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### **3.1 Introduction**

This chapter describes the development of the vegetation dynamics module, the land-use decision-making module and the production evaluation module, which, along with the population dynamics module, comprise the land-use model. Initially, the ethnographic background of the Kantu' land-use practices are described. Following that, the approach used to simulate some essential features of the Kantu' land-use systems are described. The population dynamics module has been described in the previous chapter, and the major links between the population dynamics module and the various parts of the land-use model are identified. The land-use model is very detailed by comparative standards because it includes a more detailed representation of the human system than in other models of this kind. Despite that, the descriptions of the model in this chapter emphasise the general principles of the approach. A complete account of the various modules within the land-use model can be found in the program codes and documentation in the Appendix II and III.

### **3.2 Ethnographic background of the Kantu': swidden system**

#### **3.2.1 Environment**

The Kantu' longhouse of Tikul Batu has a territory of 10 km<sup>2</sup>. The territory is generally flat to undulating with a few hills located mainly near the southwest border. Two main rivers, the Empanang and the Kantu', flow through the study area (see Figure 1.1). The rivers are an important transport route for travel to swiddens and to other locations in the region. The land along the riverbank is occasionally flooded but usually only for a short period, and dry-rice is planted within the river flood-zone's. The area generally experiences a large annual rainfall, and Dove (1985b:42-43) reported that during 1975, Tikul Batu received about 4290 mm. The rainfall is generally distributed evenly throughout the year so there are no distinct

wet or dry seasons. Continual rainfall combined with the absence of a long dry season means that burning cleared swiddens is usually difficult. Nevertheless, burning is a crucial part of the swidden system because it releases nutrients from the plant dry matter which become available for the current plants (Uhl and Jordan, 1984:1485). Dove (1981:91) asserted that the continual difficulty of achieving a thorough burning was the most serious limiting factor in the Kantu' swidden system.

### **3.2.2 Economy**

At the time of Dove's study, the Kantu' lived a largely subsistence lifestyle. Apart from cultivating swidden for rice, other subsistence activities include fishing (mainly in the Empanang and Kantu' river), hunting (especially deer, pig and monkey), the gathering of edible non-cultigens (e.g. bamboo shoots, ferns and fungae), and raising pigs and chickens. The Kantu' also engaged in some non-subsistence (i.e. cash-earning) activities including working for wages in nearby Sarawak, growing pepper, and trading and tapping rubber. Pepper was grown in small gardens (c. 200 plants) near the longhouse. The commitment to pepper cultivation, however, fluctuated depending on the market price of pepper. In addition, the high capital investment (mainly for fertiliser) and high intensity of labour associated with pepper cultivation discouraged some households from relying on pepper as a source of cash.

Rubber was generally a more desirable way to earn cash compared to pepper cultivation. This tree crop has been successfully integrated into the swidden system by the Kantu' (Dove, 1993) and other swidden communities in Indonesia (e.g. Cramb, 1989b; Gouyon *et al.*, 1993; Lawrence, 1996; Pelzer, 1978). The reason for this success is that by combining rubber and swidden cultivation, the farmers can effectively utilise surplus land and labour resources (Dove, 1993:139). For example, to make a rubber garden, swidden farmers usually intercrop rubber (from seeds or seedlings) with rice in swidden plots. After the rice is harvested, the swidden is abandoned, and the rubber is left to grow with other forest species that naturally invade the plot. This stand eventually develops to form a forest whose overall morphological structure is similar to secondary forest but is dominated by rubber trees (Gouyon *et al.*, 1993; Lawrence, 1996). These 'rubber gardens' are then usually left with virtually no maintenance.

Rubber trees are tapped for latex some 10-15 years after the initial planting and continue to produce latex for another 25-30 years. The products of this tapping were rubber slabs, which were then sold to local traders. Once producing, the trees can be tapped at any time throughout the year and the Kantu' normally tapped rubber trees when there was no work in swiddens. Thus, tapping did not interfere the swidden cycle; in fact it maximised the use of labour during idle periods. In 1974, there were 66 rubber gardens, typically about 1 ha each and containing about 200-400 individual trees. Each household owned an average of almost five gardens. These gardens were spread around the longhouse territory but they tended to concentrate along the banks of major streams and rivers (being planted there for ease of transport). The mature rubber gardens closest to the current year's swidden were usually tapped in that year.

However, the overall extent of rubber gardens was generally small. At the time of Dove's study, only 8.5 % (4.4 ha) of the average Kantu' households' landholdings of 52 ha was occupied by rubber gardens (Dove, 1993:142). Thus for the Kantu', rubber was never viewed as an alternative to rice. Rubber trees were tapped only when they were in need of cash to buy tradeable goods that their subsistence agriculture could not provide (e.g. salt, soap, sugar, cooking oil, kerosene, clothes, etc.). The cash was also used to buy market rice in the event of harvest failure. This consumption-driven form of production largely explains the low intensity of rubber production among the Kantu'; and on average, only about 60 % of the mature rubber gardens were tapped and those that were, were tapped irregularly (Dove, 1993:143).

Despite engaging in some market-oriented activities, Dove (1981) suggested that swidden cultivation was the central feature of life in the Kantu' community. He further added that not only the economy, but also the settlement pattern, social structure, most of the rituals and much of the common law of the Kantu' revolved around their system of swidden cultivation (Dove, 1981:85). Before describing the swidden system in greater detail, the land tenure system, which is closely integrated with the social structure via the rules for the inheritance of land, are described in the following section.



### 3.2.3 Land tenure system and land inheritance

Access to the land resource is regulated by land tenure system. The arrangement of the tenure system involves two major social groupings; the longhouse and the households making up the longhouse. The longhouse territory sets the boundary within which all resident households are entitled to claim land and thus exclude non-resident households. A household can acquire the 'ownership' of land by felling a section of primary forest to make a swidden. This ownership confers a primary right to re-use the secondary regrowth (fallow) plot to make further swiddens, or to lend, give, loan or sell the land<sup>1</sup>. The land tenure system based on this 'first feller' principle is, in fact, not exclusive to the Kantu' and is common in many swidden communities in Borneo and Indonesia (e.g. Appell, 1986; Cramb, 1989a; Ostergaard, 1994). Felling primary forest generally requires more labour than felling secondary forest. For the Kantu', Dove (1985b:377) estimated that the labour required to fell primary forest was three time larger than for secondary forest. Therefore, the permanent ownership rewarded to the feller is essentially recognition of the investment of labour (Shepherd, 1991:155).

There are a few other rules that regulate the parts of the primary forest where a household can make a claim. The 'initial' claim is made by slashing any part of a swidden-size section of primary forest. The act of slashing is strong enough to guarantee an exclusive right to that forest section for three successive years or until the forest is finally felled and planted with rice, which marks the permanent claim to the land. If for any other reason, the household fails to use the slashed section for that third year, that household has to renew slashing in the next season. Therefore, a household can clear any primary forest that has not been slashed previously by another household.

If a section of primary forest has not been slashed but it is adjoined by either a secondary forest or an active swidden belonging to another household, this section is proscribed to clearing by all other households. In other words, the owner of

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<sup>1</sup> Under this land tenure system, fallowed swiddens are in fact owned by households. Governing authorities often fail to recognise the operating of this traditional land tenure system. They often regard fallow lands as 'abandoned' or 'unowned' and therefore these lands belong to the state by default (Dove, 1988).

secondary forest plot possesses 'the rights of adjacency' to the adjoining primary forest. There are further detailed rules about the rights of adjacency. For example, the rights of adjacency usually secure the primary forest section adjoining the uphill edge of either secondary forest or a swidden for a household. Other rules are also in place to prevent a household from dominating sites along riverbanks, because these areas are universally desirable for fertility and transport reasons. The implication of the rules related to the rights of adjacency is a pattern of land usage of the Kantu', wherein each household clears one swidden along the banks of a river or stream and then clears the successive-years swiddens inland and hence uphill from the waterway. For a more detailed description of the rights of adjacency, see Dove (1985b: 56-62).

The principles of land inheritance, which were first introduced in Chapter 2, are that upon the departure of a married child through household partition, the rubber gardens and other property are divided between the parent's and the child's household, but this does not apply for secondary forest (fallow) plots. The primary rights to re-use the secondary plots are shared between the parent household and one or more children households that are created through partitions (excluding out-marrying children). However, the Kantu's custom, limited the sharing of fallow land to 'one branch' only. As illustrated in Figure 3.1, this rule means that while household A must share the land with B1 and B2, it cannot share the land with households that result from further partitions of household B1 or B2, that is, households C1 to C4.

Dove (1985a:172) asserted that the above-noted rule could disadvantage households that came into existence at a later stage in the development of the community when the area of primary forest had declined. However, Dove (1985a:172) also mentioned that in 'one or two instances' land was formally divided between the parent (A) and children households (B1 and B1), so that the latter households (B1 and B2) could share the land with their children households (C1-C4) without violating the 'one branch' rule). Dove's remark that such division occurred in 'one or two instances', of course, leaves us with the question regarding the generality of such timing of land inheritance. I interpret this as that the postponement of land inheritance until the emergence of the grandchildren generation in effect allowed sufficient time for all

the children to be married, so that their post-marital residences were known at the time of inheritance. Therefore, the children who were not eligible to inherit land (i.e. out-marrying children) were known with certainty. During the field visit to the study area, the presence of time lag between household partition and land inheritance was observed; newly-formed households generally still shared lands with the parents, while long-established households had formally acquired lands inherited from the parents.

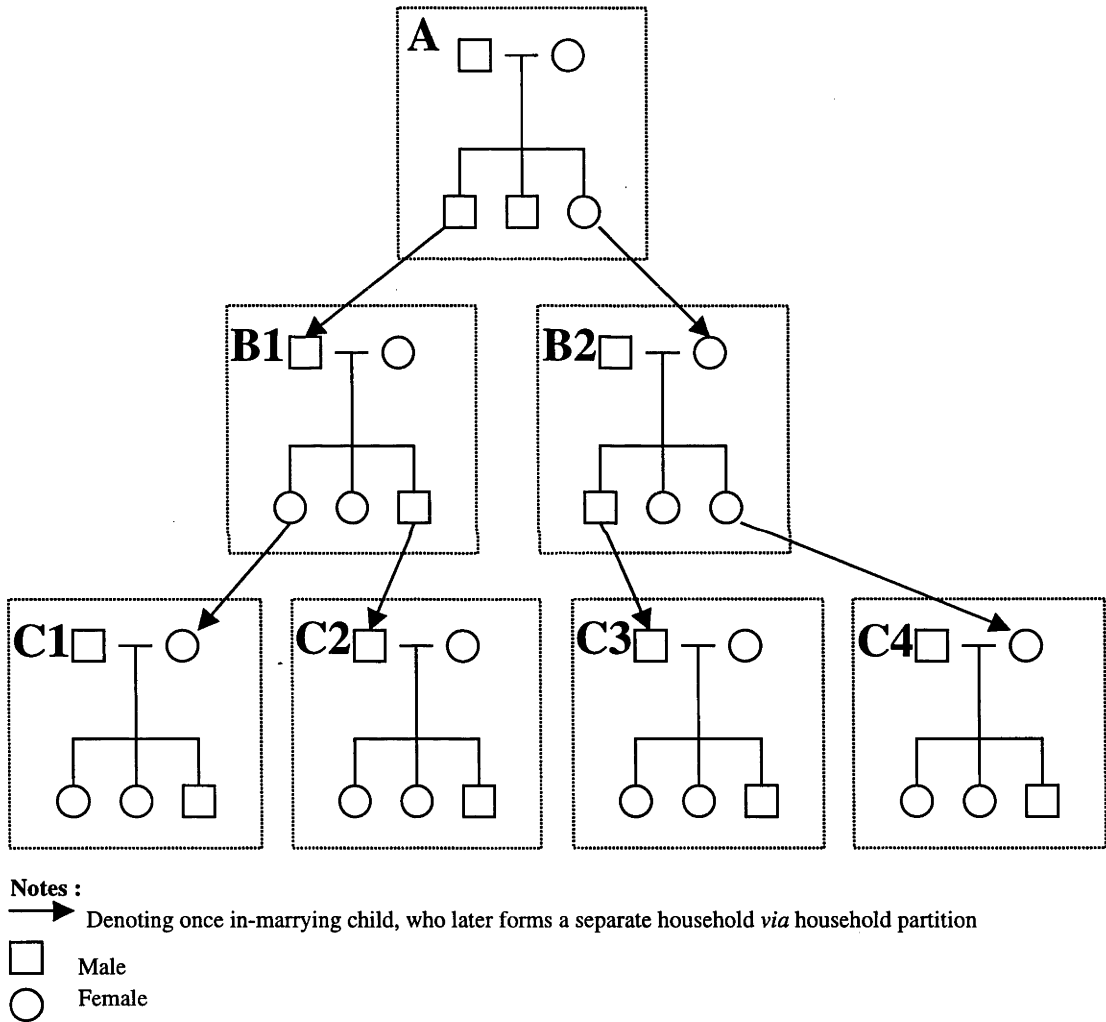


Figure 3.1 Household partition and rules of inheritance for secondary forest (fallow) plots. The ‘one branch’ rule stipulated that household A must share land with B1 and B1, but not with C1-C4. But once the C1-C4 generation came into existence it was possible to formally divide the land between household A, B1 and B2. Household B1 and B2 could then share the land with their children (C1-C4) without violating the ‘one branch rule’. To express the relationship between two successive generations, the terms ‘senior’ household referring to household A and ‘junior’ household referring to household B1 and B2 are frequently used throughout this thesis. The diagram is adopted from Dove (1985a: 173). Note that sex does not determine the eligibility to inherit land or household property in general; the main determinant of the eligibility is post-marital residence.

### 3.2.4 General aspects of the Kantu' swidden cultivation system

The Kantu' grew a variety of rice in one swidden, intercropping them with several non-rice cultigens (e.g. maize, cassava or vegetables). Rice was planted for one season only, and after harvest, the swidden was abandoned. The rice was produced for consumption only. Any rice surplus was stored or used to help other households who had experienced a bad harvest; the surplus rice was never sold. The rice yield per hectare varied enormously largely depending on whether the swiddens were made in primary forest, secondary forest or swampland, which yielded on average about 460, 750 and 1300 kg of unhusked rice per ha respectively. Note that the higher average productivity of secondary forest compared to primary forest, is caused by the difficulty in burning primary forest and is not a matter of inherent differences in soil fertility.

Each Kantu' household tended to make multiple swiddens each year, and households made an average of about 2.3 new swiddens each year and the average extent was about 2 ha. One consequence of this practice noted by Dove (1981:85) is that the various swiddens encompassed many different microenvironments and this minimised the overall dependence upon a single type of microenvironment. Thus, a household commonly mixed its swiddens between primary and secondary forest, between dry-land and swampland<sup>2</sup>, and between land within and above the riverine flood-zone.

The entire cycle of swidden cultivation consisted of the following tasks: (1) site selection (2) slashing undergrowth and small trees, (3) felling larger trees, (4) drying, (5) burning, (6) planting rice and other crops, (7) weeding, (8) guarding the swidden from predators, (9) harvesting (10) carrying the rice from the fields to the longhouse. Of these tasks, site selection is particularly important in this study because it directly affects the spatial and temporal dynamics of the landscape.

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<sup>2</sup> There are natural swamplands in the study area, but the extent is relatively limited compared with dry-lands. Cultivating swidden in swamplands is slightly different from that in dry-lands (see Dove, 1980 for the complete accounts of this). Nevertheless, this particular type of swidden cultivation is not included in the model, so the entire description of swidden cultivation in this thesis refers to the swidden cultivation in dry-lands.

### 3.2.5 Site selection

In selecting the site for a swidden, the Kantu' considered a range of factors including the ownership of the site, forest type, drainage and flooding characteristics, its location in relation to the longhouse and other agricultural lands held by the household. Decisions were also guided by omens, and in particular, the flights and calls of seven species of 'spirit birds' (Dove, 1985b:27,86-91). At this stage, the observing omen was conducted to accept or reject a prospective swidden site. I will not further discuss the role of omens except assuming that it reflects a random factor in the site selection process. With regard to ownership, under the Kantu' land tenure system, secondary forest is always under ownership of either one household or a group of households which are related through household partitions (see section 3.2.3). However, it was possible for others to use that site by (1) borrowing for one season only, (2) temporarily exchanging a section of their own forest for the desired section held by the other household, (3) permanent exchange (3), renting, and (4) buying.

Dove's description implies that the temporary transfer of land, especially borrowing and temporary exchange of land was mainly driven by the need to obtain a plot in a suitable location for the current season (e.g. Dove, 1985b). Similar practices regarding the temporary transfer of land has also been reported by Cramb (1989a:284-286) and Padoch (1982:46-49) in study sites in the Iban longhouses of Sarawak. Padoch (1982:46) also asserted that the temporary transfer of land could have a more important role by facilitating more equitable access to land among the land-rich and land-poor households which then minimised the over-utilization of some plots by land-poor households. Meanwhile, primary forest was to some extent an open access resource, and households could clear any primary forest except within areas where the rights of adjacency came into play (see section 3.2.3).

One tenet of the Kantu' swidden system is the strategy of diversification. As part of this strategy, each Kantu' household ideally made at least one primary forest and one secondary forest swidden each year (Dove, 1985b:78). The tendency to diversify forest coverage was reflected in the household activity each year (see Table 3.1).

Table 3.1 Diversification of forest type based on 26 cases of households who made multiple swiddens in 1975 and 1976.

	Number of swiddens made in 1975 or 1976		
	2 swiddens	3 swiddens	4 swiddens
Incidence of households who made at least one swidden in primary forest and one swidden in secondary forest	54 %	92 %	100 %

Source: after Dove (1985b: 78).

In deciding between primary or secondary forest for a swidden, the following aspects were considered. The benefit of making swidden in primary forest is primarily the permanent ownership given to the feller. Nevertheless, the arduous and potentially dangerous task of clearing primary forest means that only households with sufficient male adults can make a swidden in a primary forest. Therefore, the absence or illness of the male members of a household can greatly affect the ability of a household to clear primary forest. Likewise, households with a larger number of males have a greater opportunity to accumulate land, as shown by the particular case involving two households where the one which begat sons 10-15 years earlier had accumulated 14 plots more than the other household (Dove, 1985b:80). Given the reward of permanent ownership Dove suggested that, in some circumstances, the driving force to clear primary forest simply stems from the anxiety of some land-hungry households to acquire as much land as possible (Dove, 1985b:78).

Nevertheless, making a swidden in primary forest was difficult because of the above-noted labour requirement, but also because it was difficult to completely burn a primary forest (see section 3.2.4). Thus, secondary forest was generally a 'safer' option. When the Kantu' attempted to make a swidden in a secondary forest, the length of the fallow was a primary consideration for several reasons. Firstly, they avoided sites with dense shrub cover which is common in the early successional stages following clearing, and preferred sites where the girth of the trees was at least that of a 'mans head' (Dove, 1985b:81). This would have minimised the amount of clearing necessary. Interestingly, the Kantu' 'measured' the fallow by the change in vegetation structure, rather than the elapsed time, and this approach would naturally integrate the various site factors, e.g. fertility, which influenced the length of fallow which was necessary to restore/maintain site fertility. For example, the Kantu'

noticed that in general, swiddens made in five years or less fallow lands typically yielded less rice and Dove estimated that in this environment, a fallow period of as little as seven years could be maintained without leading to environmental degradation (Dove, 1981:94).

The location of new swiddens was chosen, as would be expected, based on distance to the longhouse and the other land holdings, the distance to rivers because those lands were generally more fertile, and because the rivers were a primary transport route (Dove, 1985b: 63). Another important factor was the proximity of the site to the household's swidden from the previous year ('last-year swidden'). This facilitated easy access to some non-rice cultigens that could be harvested up to six-months after the abandonment. Secondly, when the swiddens were located far away from the longhouse, the Kantu' usually constructed a swidden hut in which the household member/s slept during the most intensive swidden work to save on the travel time involved in walking to and from the longhouse (Dove, 1981:87). By locating the new swidden near the last-year swidden, the farmers could reuse the old swidden hut. This preference was reflected in the actual practice. For example, of the 35 new swiddens made in 1975 and 1976, 21 of these were close to the households' last-year swidden, and 12 were actually adjacent (Dove, 1985b: 65). The same preference was also reported for the Kenyah of East Kalimantan (Colfer *et al.*, 1997:98).

While each Kantu' household preferred to locate new swiddens near the last-year swidden, they also tended to spatially separate two or more swiddens that were made in the same year (Dove, 1985b: 69). Again, this practice can be viewed as an attempt to maximise swidden diversity. By locating swiddens belonging to the same household far apart, the swiddens were likely to have different microenvironments, which could reduce the risk associated with dependence upon a single microenvironment. In fact, the proximity to the household's other swiddens was regulated by formal prohibition specifying the minimum distance between active or 'current' swiddens belonging to the same household. The Kantu' said that two swiddens should be separated by at least three intervening swidden-sized sections of forest or two sections plus a river or stream. While some Kantu' maintained that this rule was no longer in force, Dove observed that the practice to locate two or more

swiddens in close proximity was rare. Of the 26 cases of households that made multiple swiddens in 1975 and 1976, the incidence of swiddens located within the proscribed distance occurred only in three cases.

The final consideration of location is the proximity to swiddens belonging to other households. One advantage of having several households cultivate swiddens in the same vicinity is that it facilitated labour exchanges between the households by minimising the amount of travel time involved. In this regard, Dove's data (1985b:72) suggest that a pair of households with at least one adjoining swidden were more likely to participate in 'reciprocal' work (see section 3.2.6). Another important advantage of having a cluster of swiddens is that it potentially reduced the severity of pest attack since the pest attack would be spread over larger area (Dove, 1985b:73).

### **3.2.6 The use of labour and cultivation schedule**

While swiddens were often cultivated largely by the household's labour, extra-household labour was also used in many circumstances (Dove, 1981:87). Extra-household labour was mainly drawn from other households in the same longhouse (Dove, 1985b:21), but labour from other longhouses was also used occasionally (Dove, 1985b:26). Recruitment of the extra-household labour took place through the following arrangements. In a 'gift labour' arrangement, one household gave its labour freely to another closely related household. Under a 'cooperative labour' arrangement, a group of households formed a working group in which all the households work for one household on one day and then for another household on another day and so on. The 'reciprocal labour' arrangement involved the exchange of labour between two households where one man-day of work is reciprocated by one man-day of work. There was also a 'work for wages' arrangement where a wage was paid in rice or cash. The wage standard at the time of Dove's study was about 3.5 kg of unhusked rice or 400 rupiahs per person per day (Dove, 1984:115).

Dove's data (1985b:22) show that extra-household labour was never used to select, burn or guard a swidden, but was sometimes used during slashing, felling, weeding and carrying, and was nearly always used during planting and harvesting (Dove,



1985b:22). This data indicates that, to some extent, each household was partly dependent on the other households to complete all the cultivation tasks. Apart from that, Dove (1981:87-88) suggested that the use of extra-household labour also served two other functions. Firstly, to re-distribute rice surpluses from well-off households to households who experienced a bad harvest. Secondly, to maximise the use of household's labour during any idle periods by working for other household who temporarily experienced a shortage of labour.

The estimated labour requirements were much larger for swiddens made in secondary forest compared to primary forest (see Table 3.2). Both types of swiddens differed markedly on the amount of labour spent for felling, weeding and harvesting. Felling primary forest required more labour because there were more large trees, and the wood was also generally denser, and hence harder to cut (Dove, 1985b:126). Weeding was not generally a major problem in primary forest swiddens but it was a serious problem in secondary forest swiddens. Dove (1985b: 223) attributed this to the greater prominence of herbaceous plants in secondary forest than in primary forest. The root systems of the herbaceous plants that survived burning combined with the invasion from the surroundings hastened the establishment of herbaceous weeds in secondary forest swiddens. Furthermore, harvesting in secondary forest swiddens needed more labour because their yields were higher than primary forest swiddens (see section 3.2.4).

Another important aspect of swidden cultivation is the timing of each cultivation task (Figure 3.2). The determination of the timing was based on several factors including the ideal interval between successive tasks and the 'reading' or prediction of key environmental characteristics that were believed to signal the appropriate time to do a particular task. For example, slashing and felling of swiddens made in primary forest were done earlier than those made in secondary forest because of the need to get an ideal drying period in order to achieve a thorough burning. In general, the swiddens should be left long enough to be completely dry but also be short enough to prevent regrowth, especially in secondary forest swiddens. The higher amount of biomass in primary forest plots means that these plots need a longer period for drying. Therefore, since the timing of burning was generally limited to a

Table 3.2 Labour input per hectare throughout the swidden cycle (person work-days/ha).

Tasks	Swidden Type	
	Primary forest swidden	Secondary forest swidden
Selecting	0.6	0.8
Slashing	8.0	9.2
Felling	12.0	4.0
Burning	1.4	3.6
Planting	12.9	14.7
Weeding	0.0	48.8
Guarding	1.0	4.0
Harvesting	29.9	49.2
Carrying	3.8	4.9
Swidden hut making	3.2	4.0
Tool making	15.5	24.6
Totals	88.3 work-days/ha	167.8 work-days/ha

Source: Dove (1985b:377)

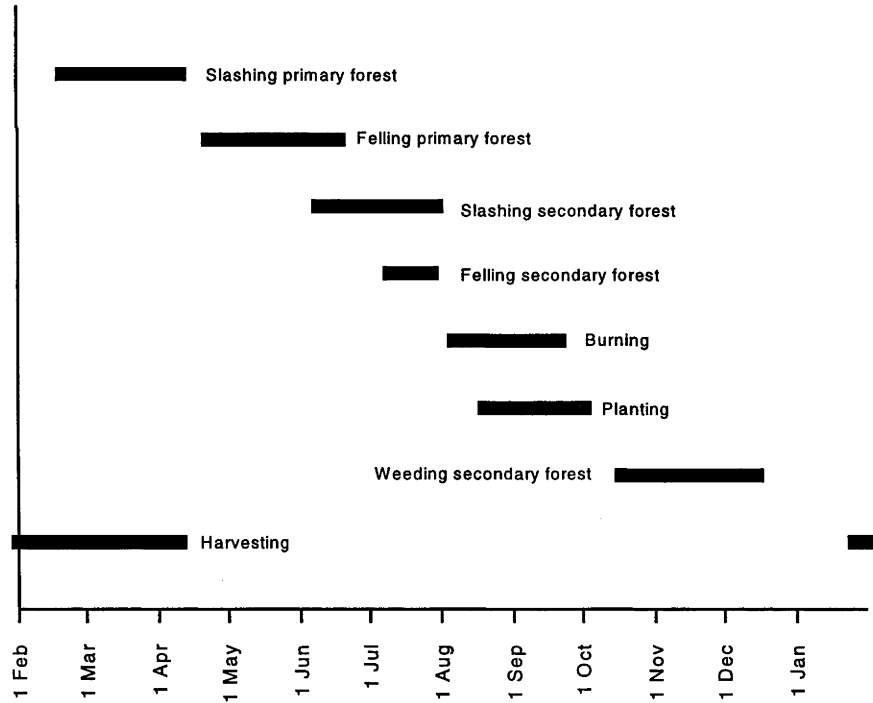


Figure 3.2 The periods within which some core cultivation tasks were performed. The figure is constructed based on Dove (1985b).

relatively short period of drought, the slashing and felling of primary forest were done earlier than in secondary forest. The Kantu' said that the ideal felling-burning interval was 2.5-3 months in primary forest swiddens and one month in secondary forest swiddens (Dove, 1985b: 128).

The Kantu' used traditional methods to make some predictions to determine the right timing of each cultivation task. One crucial piece of information that they needed to predict was the length of drought. The methods that they used included using key environmental indicators such as the fruiting cycle of candlenut trees. Or, using simple probability logic based on the recent past occurrence of lengthy drought, that is, if a lengthy drought has occurred in the last two or more years, they expected that the likelihood of a lengthy drought in the coming year was relatively low. Such information also affected their overall swidden strategy, i.e., whether to cultivate swiddens that required lengthy drought, i.e. primary forest swidden, as opposed to those that do not, i.e. secondary forest. Other environmental indicators used were the falling of durian fruits signaling the end of the drought, which is the appropriate time for burning (Dove, 1985b:140-141). The correct time for planting was determined mainly using a locally-developed lunar calendar where the best timing for planting was during the seventh and eighth month (Dove, 1985b:209-214). Nevertheless, other factors were also considered including the length of the burning-planting interval. This interval should not exceed one week in secondary forest swiddens to prevent the field being dominated by weeds. However, an interval of between one to two months was required in primary forest swiddens in order to dissipate the toxic residues from the burn, which can kill rice plants. The Kantu' said that this toxic residue was peculiar to primary forest swiddens and its injurious impact was lessened with time and rainfall (Dove, 1985b:146).

Furthermore, the timing for weeding was entirely a function of the timing of burning and planting; the former determined when the weeding begins and the latter determined when it ends. The Kantu' said that weeding could not begin until the weeds were tall enough to be grasped and plucked from the ground by hand. The average time required to attain this size was on average about six weeks after burning. Weeding ended when the rice panicles emerged, which occurred, at the latest, approximately fourteen weeks after planting. Therefore, the maximum

duration of the weeding season was typically eight weeks (Dove, 1985b:237). Similarly, the timing for harvesting depended on the timing of planting. Rice can be harvested as early as 157 days after planting. Once the rice plants have attained maturity, they have to be reaped quickly to minimise losses due to lodging, shattering and predation. Accordingly, households tended to intensify the use of labour during this period. The reported maximum planting-harvesting interval was 190 days, thus the maximum duration of reaping was about 33 days (Dove, 1985b:318-319).

### **3.3 Description of the land-use model**

The foregoing sections have described in detail the economic, ecological and socio-cultural aspects of the Kantu' land-use practices. This study attempts to represent the key processes of those land-use practices in a simulation model. Specifically, the model is designed to simulate land-use decisions made by individual households and to examine their long-term consequences on the landscape and the welfare of the community. Various processes simulated by the model are organised into four modules: population dynamics, land-use decision-making, production evaluation, and vegetation dynamics module. The sequence of calling for each module is presented in Figure 3.3. This section will firstly describe the structure of the data and then the detailed description of each module.

#### **3.3.1 Data structure**

The model simulates a system consisting of human components (persons and households) and physical components (blocks, plots and the landscape). The core attributes of the components including the links between them are presented in Figure 3.4-a. The person and household components have been introduced earlier when explaining the population model in Chapter 2. The model uses a hypothetical landscape presented as a grid of 50 x 50 'blocks', each of which has an area of 0.5 ha. The area of the simulated landscape is thus 12.5 km<sup>2</sup>, just over the estimated territory of the Tikul Batu longhouse (10 km<sup>2</sup>). For the current application, the landscape initially consists of free-access primary forest blocks (Figure 3.4-b). A plot is a management unit, which consists of a group of blocks.

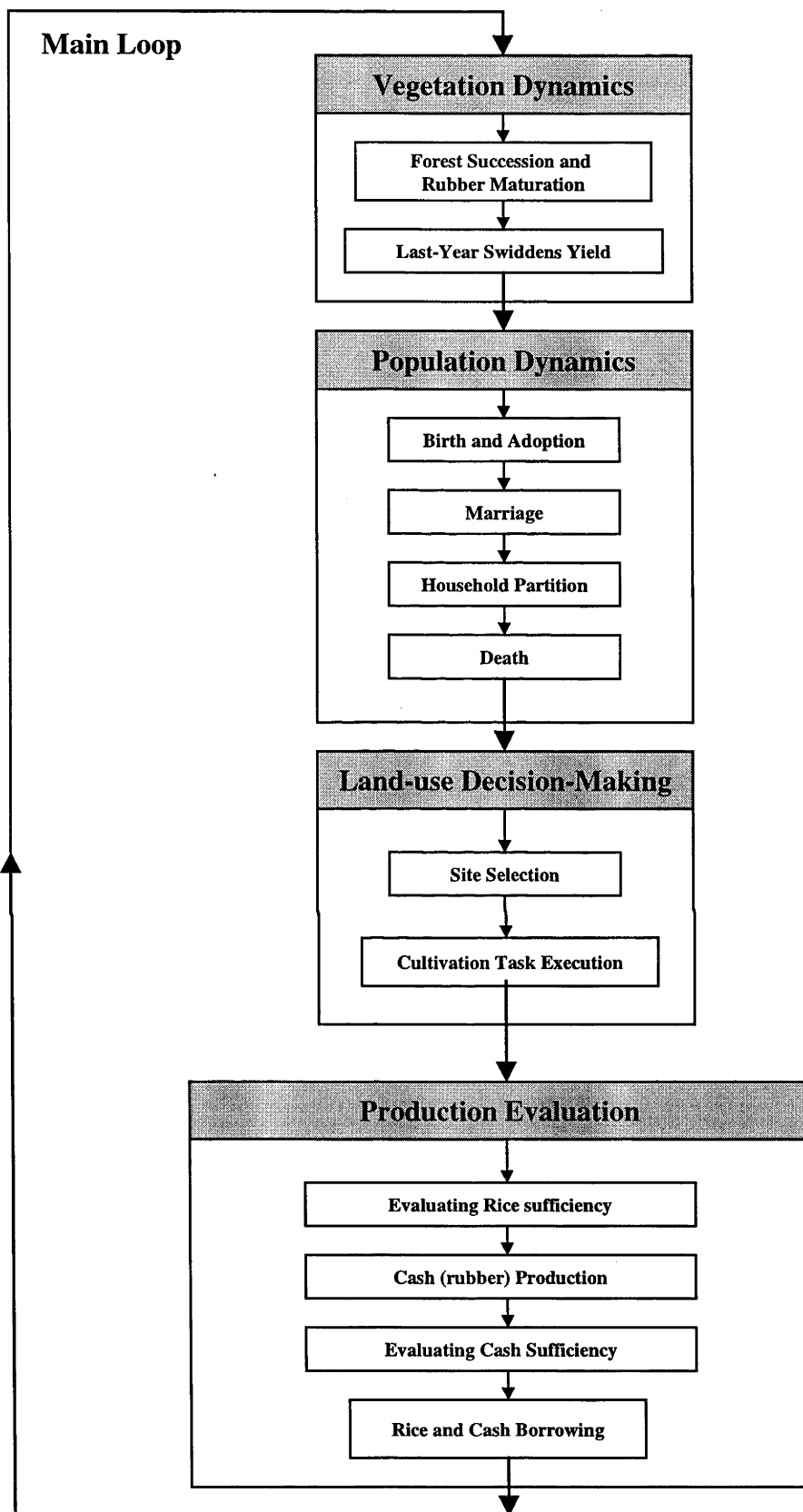


Figure 3.3 The sequence of calls of the main processes during the simulation



Person	Household	Block
<ul style="list-style-type: none"> <li>• Identity number</li> <li>• Household affiliation</li> <li>• Age</li> <li>• Sex</li> <li>• Biological father</li> <li>• Biological mother</li> <li>• Adoptive father</li> <li>• Adoptive mother</li> <li>• Marital status</li> <li>• Spouse</li> <li>• List of children</li> <li>• Years since last birth</li> <li>• Residence type</li> </ul>	<ul style="list-style-type: none"> <li>• Identity number</li> <li>• Head</li> <li>• Heir</li> <li>• Senior household</li> <li>• List of junior households</li> <li>• List of members</li> <li>• List of owned plots</li> <li>• List of cultivated plots</li> <li>• List of borrowed plots</li> <li>• Rice stock</li> <li>• Cash stock</li> <li>• Rice debt</li> <li>• Cash debt</li> </ul>	<ul style="list-style-type: none"> <li>• Identity number</li> <li>• Coordinate location</li> <li>• Plot affiliation</li> <li>• Vegetation type</li> <li>• Years since disturbance</li> </ul>
		Plot
		<ul style="list-style-type: none"> <li>• Identity number</li> <li>• List of blocks</li> <li>• Owner</li> <li>• Tenant</li> <li>• Year acquired</li> <li>• Method of acquisition</li> </ul>

Figure 3.4-a Attributes of the main components of the model; not all attributes are shown.

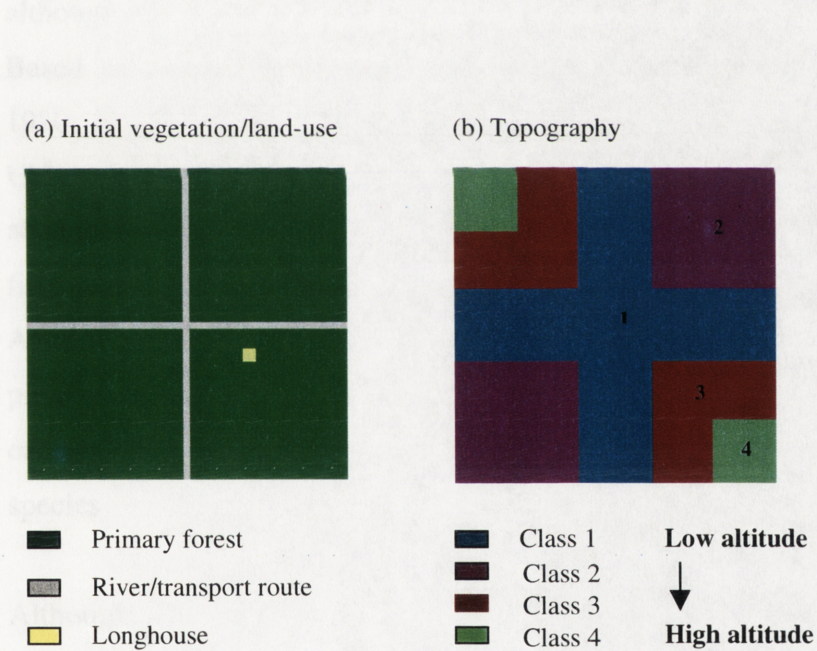


Figure 3.4-b Initial landscape configuration. The landscape is classified into four altitudinal classes. The order of the classes corresponds to increasing altitude.

The plot is formed for the first time when primary forest is cleared for swidden. In this event, a group of blocks is taken out from the free-access land pool and they are placed under the ownership of the feller household. The ownership of a plot may change upon the event of land inheritance. The model tracks the owner of the plot and the household managing the plot, because the plot can be lent to other households. The term 'block' and 'plot' used in describing the model refer to their specific meaning as explained above.

### 3.3.2 Vegetation dynamics module

Swidden cultivation can be seen as both a resource utilisation activity as well as a form of anthropogenic disturbance. With the passage of time following a disturbance, a site undergoes a series of changes in the structure and composition of vegetation through a process called secondary succession. Some generalisations can be made about the structural changes of vegetation during the course of succession, although the floristic array is likely to vary in different places (Whitmore, 1982). Based on several succession studies in Kalimantan/Borneo (e.g. Kartawinata *et al.*, 1980; Mackie, 1986; Ohtsuka, 1999) and elsewhere (e.g. Saldarriaga *et al.*, 1988; Uhl, 1987), these changes can be summarised as follows. Following the abandonment of a swidden, the site is dominated by herbaceous life forms for the first year or so. The dominance would shift to shrubs by the third or fourth years. After that, a forest structure with trees dominating the site starts to emerge. The pioneer (or light-tolerant) trees, initially dominates the forest. Later, following canopy closure, shade-tolerant tree species would progressively replace the pioneer species.

Although succession implies a process of continuous change in the species patterns and vegetation community characteristics, it is convenient to view the community as making a transition from one 'state' to another (Kessell and Potter, 1980:228), following the idea originally developed by Clements (1936). In this regard, it is interesting to note that swidden farmers also recognise the sequential vegetation changes in the course of succession and express them using locally-developed nomenclatures classifying the vegetation into several states (Figure 3.5-a). Generally, swidden farmers do not judge the state of vegetation by its age but its

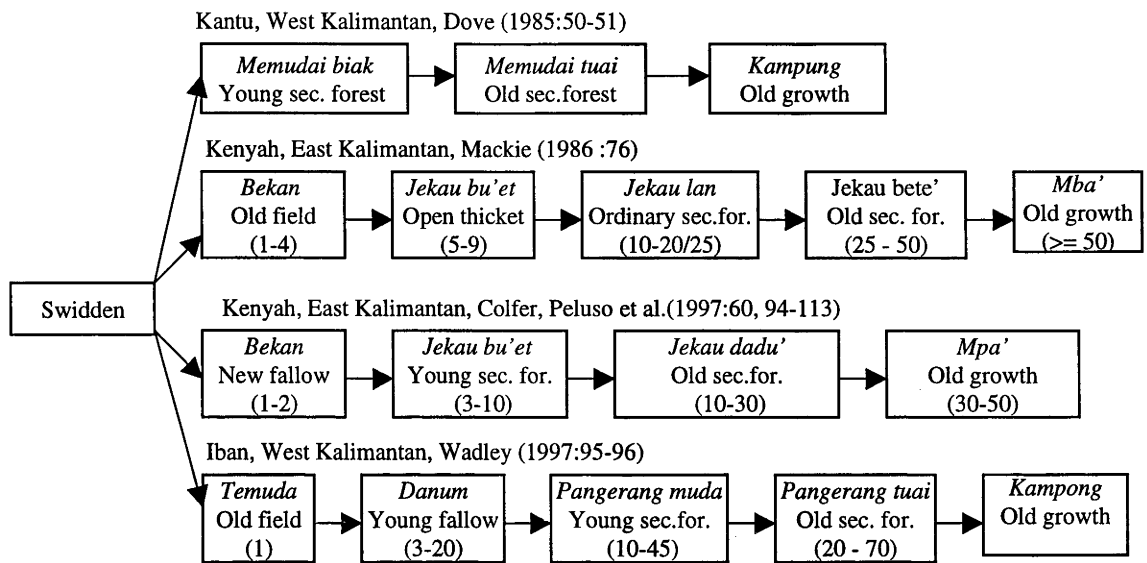


Figure 3.5-a The generalised sequences of vegetation changes following swidden abandonment in selected swidden communities in Kalimantan. Local names denoting vegetation ‘states’ are printed in *Italics*. When available, the estimated age of vegetation in each state is given in bracket.

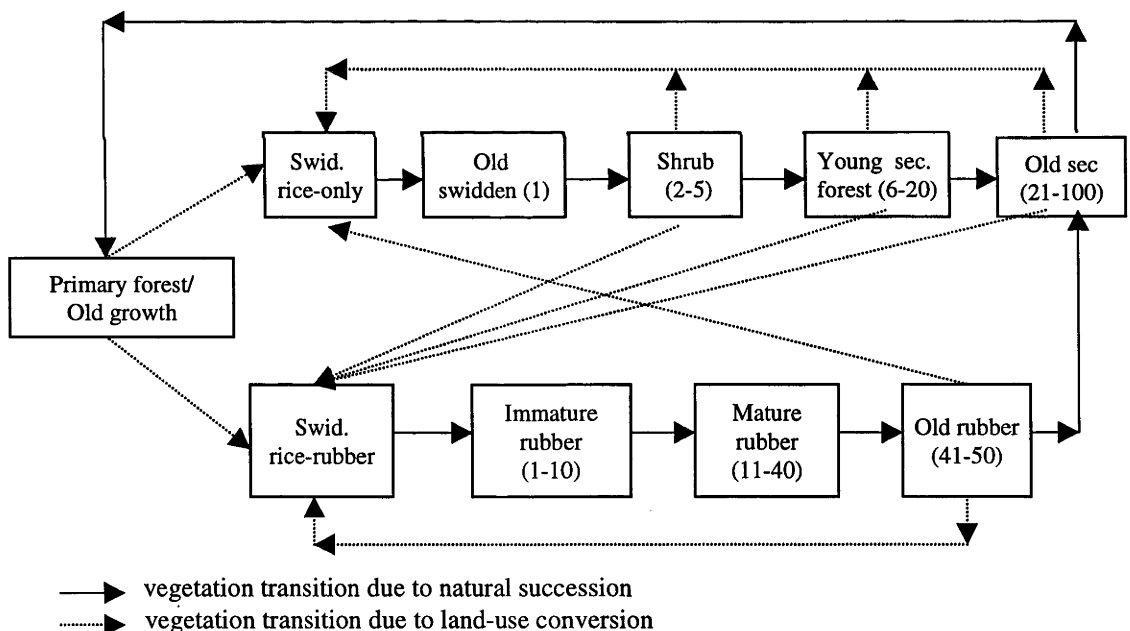


Figure 3.5-b The sequences of vegetation changes simulated by the model. The age of vegetation, i.e. years since last abandonment is given in bracket. Note that the model does not allow conversion to swidden from old swidden, immature rubber or mature rubber plots.



appearance, such as the size of the largest tree in a given stand of forest (Dove, 1985b:51). In this way, the variation in microenvironments that results in differing rates of recovery among stands of the same age is taken into account.

This model simulates the vegetation dynamics of landscape using a state-transition approach. As depicted in Figure 3.5-b, in the absence of disturbance, the vegetation makes a series of transitions from old swidden to old secondary forest. The timing of the transition is simulated deterministically as a function of the years since the last clearing. The type of state and duration in each state are determined subjectively drawing from the reported data presented earlier in Figure 3.5-a. In principle, it is assumed that swiddens are cultivated for one year only and after that, they are left in fallow. The model specifies two paths of succession: following the abandonment of a swidden planted by rice only and swidden where rice is intercropped with rubber. Intercropping rubber with rice is the only method for rubber planting in this model. After a swidden is abandoned, rubber will eventually dominate the stand. Rubber maturation is also simulated as a fixed time since planting. The period to maturation is the duration commonly reported by rubber agroforest farmers (e.g. Gouyon *et al.*, 1993). Rubber can be tapped once reaching maturity and is still tappable in the old rubber state, although in the latter case the productivity is simulated to be lower. Simulation of rubber productivity will be further discussed in section 3.3.5 when explaining rubber tapping. In addition, the model sets the allowable paths of land-use conversion. All sites can be converted to swiddens except old swidden, to enforce at least one-year fallow, and immature rubber and mature rubber plots, as farmers are likely not to cut their productive rubber trees.

The major shortcoming of the approach is that it does not take into account the history of previous disturbances. Thus, for example, a block that experiences a repeated short fallow will follow <sup>the</sup> same successional path as one experiencing shortening fallow only once. To some extent, this might not be realistic, given the widely held view that repeated shortened fallow could lead to replacement of herbaceous and woody species by rhizomatous grasses and ferns (Mackie, 1986:170; Richards, 1957:392-397). Other state transition-based succession models that are able to simulate the different paths of succession under varying disturbance histories do exist; the 'vital attributes' model developed by Noble and Slatyer (1980) is one of

them. Their model simulates the vegetation replacement sequence based on a small number of life history characteristics that are vital to species establishment following a disturbance and long term occupancy in a developing community. In their model, a state is represented as a group of species. The successional path that a site would take then depends upon the response of each species to disturbance. The Noble and Slatyer model could represent, for example, the local extinction of a species when the interval between disturbances is too short. This model has been applied with satisfactory results for the Tasmanian wet sclerophyll-rainforest (Noble and Gitay, 1996; Noble and Slatyer, 1980) and mixed coniferous forests in North America (Cattelino *et al.*, 1979; Kessell and Potter, 1980). Adopting this approach, or a similar one, to improve the vegetation dynamics module in the current version of the model is a future possibility.

Another process simulated in this module is rice yield. Note that yield of a swidden selected in the current year is simulated in the beginning of the next simulation year. With reference to Figure 3.3, it is clear that the rice available for consumption or other spending (e.g. payments of wages and debts) in a given year is a function of the land-use decisions made in the previous year. The model simulates the rice yield in a very simple way, as a function of the age of vegetation (duration of fallow). In principle, the rice yield decreases as the fallow duration shortens. The duration of fallow is classified into three classes: short, medium and long fallow. The fallow length in each class and the corresponding yields are presented in Table 3.3. The yields for swiddens made in primary forest and long fallow plots approximate those reported for the Kantu' (see section 3.2.4), while the rest are assumed. The very low yield for short fallow plots is meant to reflect the observation by the Kantu' regarding the low yield of swiddens made in less than five years regrowth.

Table 3.3 Rules for simulating rice yield

Type of previous vegetation / Fallow length	Yield (kg of unhusked rice / hectare)
Primary forest	500
Short fallow (1-4 years)	300
Medium fallow (5-9 years)	500
Long fallow (>=10 years)	750

### **3.3.3 Major links from the population dynamics module to the entire model**

The population dynamics module has been described and discussed at length in Chapter 2. When the population model is run within the land-use model, it simulates the dynamics of households that are later used in the land-use decision-making and production evaluation module. In particular, the structure and composition of the households are updated in this module and this is the key factor in the land-use decision-making and production evaluation modules since it controls the demand for, and supply of, labour available for cultivation. Another major link from this module to the entire model concerns the role of a household as the unit of property holding. Through the act of land utilisation, households accumulate land and goods, e.g. rice, cash, secondary forest plots and rubber plots. While property acquisition is mainly simulated in the land-use decision-making module, property inheritance is simulated in the population dynamics module, since it is triggered by demographic event of household partition. The post-marital residence rules as presented in Chapter 2 are modified by including the consideration of the household's wealth. The following two sections outline the rules for simulating property inheritance and wealth-based post-marital residence respectively.

#### **3.3.3.1 Property inheritance**

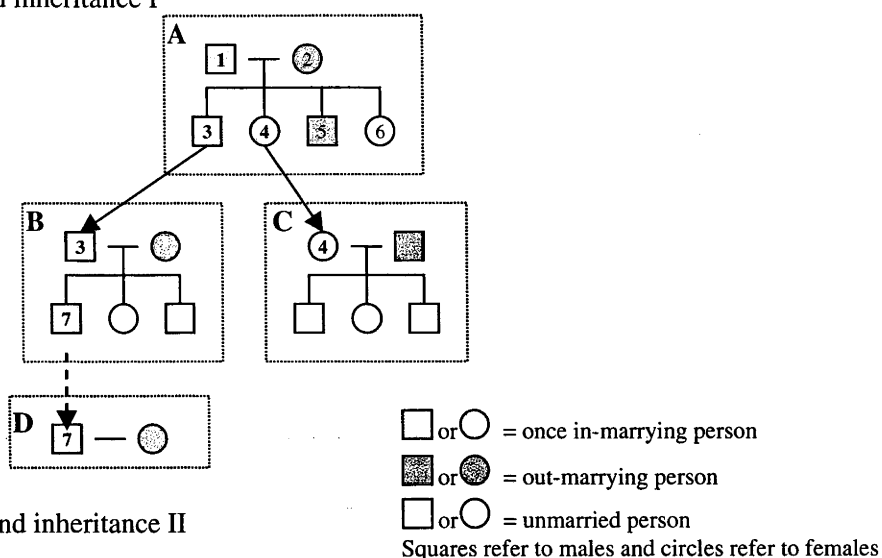
The model assumes that since all members contribute labour to the acquisition of the household's property they are also entitled to some portion of this property, except those who marry out (see section 2.2). To explain the timing of property inheritance, recall that in-marrying children, except an heir child, will eventually move out to establish a separate household *via* partition. The parents' household is called the 'senior' household and the children's household is called the junior household. In each occasion of partition, the departing child is given a portion of the senior household's rice, cash and rubber plots but not fallow (secondary forest) plots. The rice and cash are divided in proportion to the number of persons in the two splitting households. For the departing persons, this rice partly constitutes the return for their labour spent in the last year's season.

In terms of rubber plots, the allotment for the departing person is calculated by dividing the number of rubber plots with the number of eligible siblings at the time of partition. The eligible siblings consist of the departing person plus the siblings who still stay in the senior household. Thus, siblings who have left through earlier partitions are excluded, as they have already taken their part. Consequently, the number of plots inherited to each child may not be the same. Furthermore, if the number of rubber plots is less than the number of eligible siblings, a procedure is called to randomly allocate the rubber inheritance in the model. The probability of the departing person acquiring a rubber plot equals the number of plots divided by the number of eligible siblings.

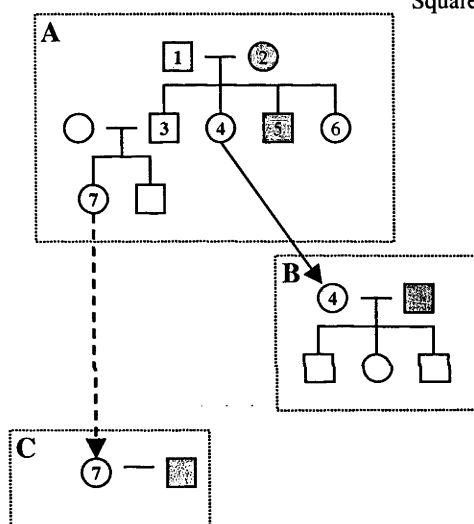
With regard to fallow plots, the model adopts the Kantu' practices of sharing the ownership of land between the senior and junior households until formal land division takes place. This means that households within a group of senior and junior households have equal access to the fallow plots. In the model, death does not trigger land inheritance. Therefore, land inheritance to a person's offspring may take place sometime after his/her death. Two demographic circumstances trigger land inheritance (Figure 3.6). Firstly, when the 'first' partition occurs in one of the junior households (B). Once each junior household acquires their part, sharing land no longer exists between the senior household and junior households. The household whose partition triggered this land inheritance (B) now becomes the senior of the newly-form household (D). The second occasion of land inheritance takes place when a partition occurs in a senior household but the departing person is the grandchild of the founders of the senior household (Figure 3.6-b). This circumstance arises when the parent of the departing person is the successor of the senior household. In this case, land inheritance is enforced so that the plots to which the newly formed household (C) will share, are those allotted for the parent, excluding the portion for the parent's siblings (B).

In both types of land inheritance (Fig. 3.6), each eligible person of a sibling-set is entitled to inherit some parts of the parent's fallow plots. Thus, allotments are made to siblings who are not yet married (e.g. person 6 in Figure 3.6), although the plots will formally remain under the ownership of the parents' household. If, at a later stage, these persons marry-in, they acquire the allotted number of plots at once when

(a) Timing of land inheritance I



(b) Timing of land inheritance II



- Denoting once in-marrying child, who later formed a separate household *via* household partition  
 - - → Denoting once in-marrying child, whose departure from the parent household triggers land inheritance.

Figure 3.6 Timing of land inheritance. From the perspective of the senior household (A) or the founder of the household (1 and 2), land inheritance is triggered by (a) partition occurring in one of the junior households, or (b) partition in the senior household with the departing person is the grandchild generation. In (a) The lands are divided among household A, B and C with an allotment set for person 6. Person 5 is not eligible. Following inheritance, household C is entitled to share land held by household B. Meanwhile, in (b) the lands are divided between household A and B with an allotment set for person 6. Following inheritance, plots that remain in the senior household are essentially the portion for person 3 (the parent of person 7).

they separate from the parent household. Since their parts have been taken, following the partition, they are not entitled to share the land of the parents' household. However, if they marry-out or never marry, the allotted land will remain in the household, thus adding the portion for the heir sibling who succeeds the household.

Meanwhile, the portion of land acquired may not be the same for each person. It is assumed that each person is entitled to parts of the land in which he/she contributes labour. This implies that plots acquired after her/his departure from the parents' household are not included. This rule would in effect take into account the length of time that they were part of the parents' household. To implement this principle, the number of fallow plots in the parents' household at the time when a person leaves the household is recorded (NumSecAtOut). The model specifies that two plots are set aside (PlotSetAside), thus they are not included in the pool of land to be divided. This would give the successor of a household a slightly higher proportion than received by other members. At the time of land inheritance, the allotment for each junior household is calculated as the NumSecAtOut minus PlotSetAside, and then the remainder is divided by the number of eligible siblings, including those who stay in the parents' household. If the allotment for a person is less than one plot, a procedure is then called to randomly determine whether the person will acquire a fallow plot. Once all junior households have taken their portion, the allotment for siblings who stay in the parents' household is calculated. Each of these people is allotted more or less the same proportion of the remaining plots.

### **3.3.3.2 Wealth-based post-marital residence rules**

In the population dynamics model, as presented in Chapter 2, the decision on post-marital residence is based on household membership status and the number of eligible siblings (see Table 2.2). When the population dynamics model is run within the land-use model, the latter rule is modified; to determine the residence of two marrying persons, the model compares the household's wealth (i.e. size of fallow land holding) of both sides. In a specific case where a marrying person has been allotted land (such as person 6 in Figure 3.6 or see the preceding section), the wealth refers to these allotted plots. Otherwise, it refers to the number of plots owned by the household. However, the existence of land sharing arrangements complicates the matter, as some households may still share lands with the senior household and

consequently the exact number of owned plots is unknown. In such a case, the model first calculates the approximate number of plots if land inheritance happened at this time, which is then used as a proxy for the size of household's land holding. In deciding the residence, a person from the household with a smaller number of plots moves to the larger one. Apart from reflecting what might be 'common sense', this rule to some extent captures what has been reported by Freeman (1971:48-50) for the Iban. He found a tendency toward out marriage, as the size of sibling set became larger, although the size of land holding was not reported. This is because in a household with a larger sibling-set, the share for each person will be smaller, which provides a strong incentive for out-marriage.

#### **3.3.4 Land-use decision making module**

The model represents a community living in a subsistence economy where the level of agricultural production is geared toward fulfilling the household's customary requirement (Sahlin, 1972:77). Family or household labour is the main means to achieve that. This mode of production can be seen in many swidden agriculture communities including the Kantu'. In this situation one expects that the demographic structure and composition of household would influence the level of agricultural production. In this regard, A.V. Chayanov (Thorner *et al.*, 1966) was among the first who related the demographic structure of a family with their level of economic activity. Chayanov noted that as a household goes through its developmental cycle (see section 2.2), the labour force and the intensity of demand continuously changes. He sought evidence on whether this continual change in household structure and composition affects the economic activity of the household. Using aggregate data on the Russian peasant farmers, he was able to demonstrate a positive correlation existed between the size of family and the level of agricultural activity, as measured by the extent of sown area (Thorner *et al.*, 1966:54-63).

The model captures this relationship by explicitly linking the demography of household with the level of agricultural production when simulating land-use decisions for rice and

rubber cultivation. The model assumes that the size of the household (i.e. the number of consumers) determines the household's demand for agricultural products. Based on this assumption, the household's rice production is driven by the demand for eating rice, seed rice and rice debt. Thus, the magnitude of the demand changes dynamically throughout the simulation. Eating rice is the sum of annual rice requirement of each household member, which is calculated from the age-sex daily rice requirement presented in Figure 3.7. The seed requirement per hectare is 38 kg (Dove, 1985b:179). Meanwhile, the magnitude of the rice debt is endogenously determined by the debt history of each household. The ability of the household to fulfill this demand depends on the household labour force, i.e. the number of workers, where a household worker is defined as a person aged 15-65 years. In this regard, the model specifies that at least two workers are required to cultivate each plot. In other words, the model imposes a maximum number of plots that a household with a given number of workers can cultivate. Furthermore, there is a specific instance when a household is enforced not to cultivate swidden at all, that is, when the accumulated rice storage is twice or more the current total demand.

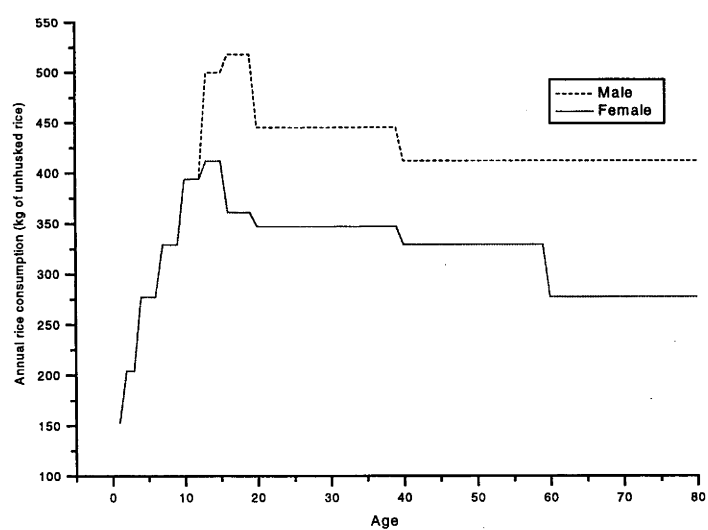


Figure 3.7 Annual consumption of rice by sex and age. Source: after Dove (1984:128).

The other major assumption in this model is that rice cultivation is always given priority over rubber production (tapping). This assumption reflects a strong preference of



households to grow their own foods. In fact, the agricultural strategy where rubber cultivation is not seen as an alternative to swidden cultivation of rice is common, e.g. as reported for the Kantu' (Dove, 1993), Mualang (Drake, 1982) and Iban (Freeman, 1992). Cramb (1989b:108) summarised the reasons for the strong preference toward swidden cultivation of rice. These included a taste preference for traditional varieties, the benefits of producing inter-cropped vegetables at low opportunity cost and the security provided against a fluctuation of market prices for rice and rubber.

Implementation of this agricultural strategy in the model is carried out by always simulating swidden cultivation of rice ahead of rubber tapping (see the flow of calls in Figure 3.3). This means that the household labour is firstly used for rice cultivation and tapping rubber is done only when there is no work in the swidden's. The Kantu's tap rubber only when there is no work in the swidden, this is what Dove called the complementary nature of swidden and rubber cultivation. (Dove, 1993:140). In the model, the labour is tracked daily (see section 3.3.4.2) which permits the model to more realistically capture this phenomenon since the model is able to identify the busy and idle days.

As described earlier, the model simulates two types of swidden cultivation; swidden for rice only and swidden where rice is intercropped with rubber. With respect to rubber planting, it is assumed that, when land is available, each household attempts to ensure the continuity of rubber production by having at least one mature (tappable) and one immature rubber plot. Rubber planting is therefore triggered soon after the last immature plot has come into production. The planting of rubber however is pursued only when the household has at least two fallow plots. This assumption would imply a relatively low rubber planting frequency. The size of a rubber plot is set to 1 hectare. Thus, if rubber is planted in a 2-hectare swidden, only half of the plot becomes a rubber plot.

Simulation in the land-use decision-making module proceeds in two major steps: (1) site selection and (2) setting the cultivation schedule and the execution of cultivation tasks, which are described in detail in the following sections.

3.3.4.1 Site selection

The rules and flow of the simulation during the site selection process are summarised in Figure 3.8. The site selection process is simulated for each household alternately, and starts with those having a larger number of plots. At the beginning of the site selection process, the household’s annual rice demand is calculated. The extent of cultivation for each household is simulated by repeatedly adding one more swidden into the household’s cultivation list until the expected rice yield exceeds the demand, or the number of swiddens attains the maximum (constrained by labour), or until there is no land (owned or borrowed) available (constrained by land). Meanwhile, the type of swidden (for-rice-only or for-rice-rubber) in each iteration is determined by the set of rules reflecting the assumption of low rubber planting intensity. Once the swidden type is set, the next simulation step is to select the geographical location for each swidden.

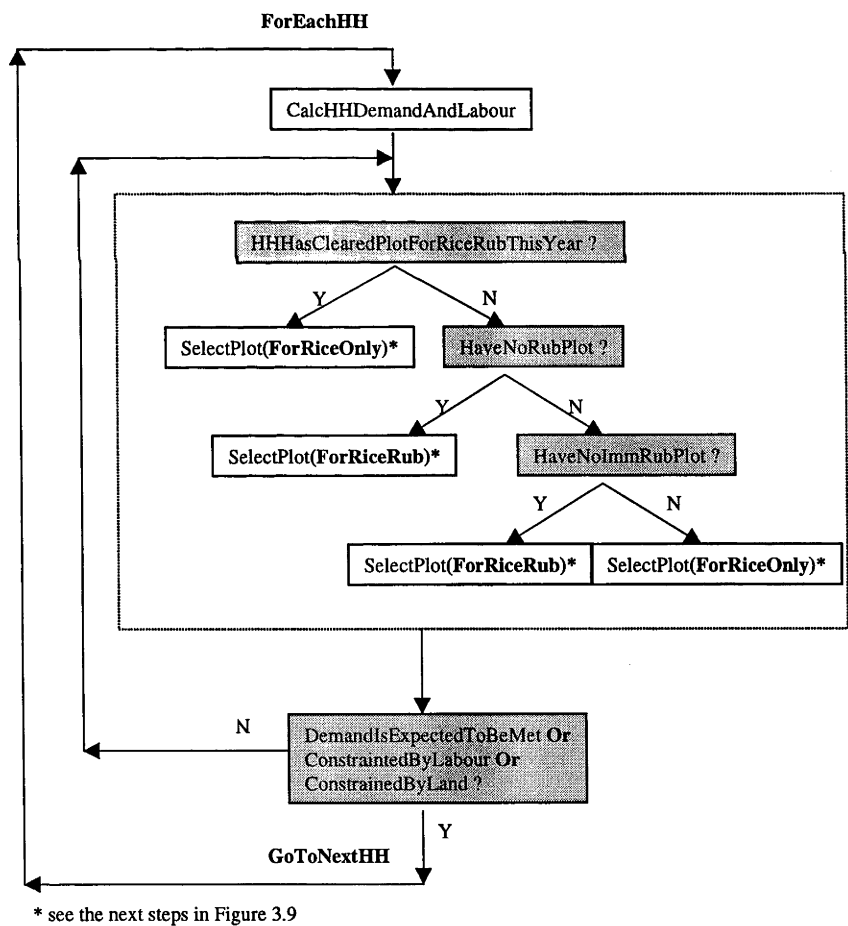


Figure 3.8 Main loop for simulating swidden cultivation

Section 3.2.5 has discussed a range of factors that the Kantu' considered in selecting a swidden. However, it is not exactly known how the Kantu' weight the importance of those factors and arrive at a final decision. In this thesis I used the Multi-Criteria Evaluations or MCE (Eastman, 1997) approach, commonly used in GIS, to simulate the geographical selection decision. In this approach, the household weighs the relative attractiveness of all potential sites and then selects the best available sites. The relative attractiveness of plots is evaluated according to criteria that reflect considerations used by the Kantu'. These include the distance to longhouse, distance to river, distance to the household's last-year's swidden(s), distance from the household's other current swidden(s), distance to other households' swiddens, site ownership, vegetation and topography. To arrive at a single measure of site attractiveness, the criteria are expressed in a numeric form and evaluated by a method known as Weighed Linear Combination (WLC). Eastman (1997: 9-5) describes WLC as a method where the (continuous) score of criteria (factors) are standardised to a common numeric range, and then combined linearly by means of a weighted average. This method is implemented in the form of a site index as described in Table 3.4.

Table 3.4 Formulation of site index

<b>Site Index = <math>F_1W_1 + F_2W_2 + F_3W_3 + \dots + F_8W_8</math></b>		
<b>Factor</b>	<b>Description</b>	<b>Weight (W)</b>
F <sub>1</sub>	Vegetation	0.3404
F <sub>2</sub>	Ownership	0.1487
F <sub>3</sub>	Distance to the household's last-year's swidden(s)	0.1487
F <sub>4</sub>	Distance to other households' swiddens	0.1487
F <sub>5</sub>	Distance to longhouse	0.0533
F <sub>6</sub>	Distance to the river	0.0533
F <sub>7</sub>	Distance from the household's other current swidden(s)	0.0533
F <sub>8</sub>	Topography	0.0533

The 'weights' (W) in this formulation reflect my assumptions about the relative importance of each factor. Meanwhile, the state of the potential sites with respect to each selection factor (F) is rated on a 1-to-5 scale, which increases with preference. Note that the site index formulated in this way permits a trade-off between the various

factors; e.g. a low score in one factor could be compensated by having a high score in one or more other factors.

The weights are assigned using a technique developed by Saaty (1977). The method, as summarised in Eastman (1997: 9-11 to 9-13), involves pairwise comparisons on the relative importance of two selection factors. Ratings to evaluate the relative importance are provided on a 9-point scale, shown in Table 3.5-a. For example, if Factor A is considered as very strongly 'more' important than factor B, one would assign 7 on this scale. If the inverse relationship prevails, that is factor A is very strongly 'less' important than Factor B, one would enter 1/7. Every possible pair of factors is compared and the derived rating is entered into a pairwise comparison matrix. For this study, although Dove's report provided empirical data on the factors used for site selection, there is no information as to the relative importance of those factors. Therefore, the assessment of the relative importance of pairwise factors in this model is based on educated guesses. The ratings on the relative importance among the selection factors used in this study are presented in the matrix shown in Table 3.5-b. An exploration on the implications of varying the weights of site index will be presented in Chapter 5.

The WLC procedure requires that the weights sum to one, which can be enforced by taking the principal eigenvector of the pairwise comparison matrix. In this study, a module in the IDRISI for Windows software named WEIGHT was used to calculate the principal eigenvector from the pairwise matrix presented in Table 3.5-b. The resulting weights (Table 3.4) indicates that the model assumes that the vegetation preference is the most important criteria, followed by the ownership preference, distance to the household's last-year's swidden(s) and distance to other households' swiddens. Whereas, the least important criteria are distance to longhouse, distance to river, distance from the household's other current swidden(s) and topographical preference.

Table 3.5-a The 9-point scale used to evaluate the relative importance between pairs of factors

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely
less important					more important			

Table 3.5-b The matrix of comparative importance of factors used to select swidden sites

Rating of the row factor relative to the column factor								
	DToHH's Other CurrSwid	DToLH	DToRiver	TopoPref	DToOther HH's Swid	DFrom HH's LastYear Swid	Owner- shipPref	Veg Pref
DToHH's Other CurrSwid	1							
DToLH	1	1						
DToRiver	1	1	1					
TopoPref	1	1	1	1				
DistToOther HH'sSwid	3	3	3	3	1			
DistFromHH's LastYearSwid	3	3	3	3	1	1		
OwnershipPref	3	3	3	3	1	1	1	
VegetationPref	5	5	5	5	3	3	3	1

The potential sites under consideration are plots of secondary forest and/or blocks of free-access primary forest. Each time a search for a swidden plot is carried out, the site index of all blocks and plots<sup>1</sup> are calculated. The procedure for assigning scores for calculating the site index is as follows. First recall that the order of the score (1 to 5) corresponds to increasing magnitude of preference with respect to a particular selection factor. The specific aspects to be measured for each selection factor are presented in Table 3.6.

In terms of vegetation, the scoring procedure begins with determination of the vegetation type preference. Vegetation preference depends on the state of household with respect to labour availability and the history of recent clearing, which are evaluated using a decision tree shown in Figure 3.9. Using those rules, when an attempt is made to clear swidden for-rice-rubber, the old rubber plot is the preferred choice. This would encourage the regeneration of rubber gardens when they become unproductive. When an

attempt is made to clear swidden for-rice-only, the model assumes that each household attempts to make one swidden in primary forest per year but this is pursued only if the household has at least one male adult, otherwise they attempt to clear fallow plots. When the attempt is to clear primary forest, the primary forest ‘blocks’ are assigned a higher score than other vegetation types. When an attempt is made to clear fallow plots, the score depends on the duration of fallow, expressed in terms of fallow class (see Table 3.3). In this case, long fallow plots are given a higher score except when there is no adult male in the household. In the latter case, the medium fallow plot is assumed to be the preferred one. In all cases, short fallow is the least preferred land. The final scoring system for the vegetation factor along with other selection factors is presented in Table 3.7.

Table 3.6 Measures used for each selection factor and summary of the nature of preference.

Site selection factor	Measure	Nature of preference
Vegetation preference	Fallow length and vegetation type	Depends on the intended type of swidden, see Figure 3.9, but generally older sites are preferable
Ownership preference	The familial link of the HH with the owner of the plot	Free-access blocks or plots owned by the HH or plots under land sharing arrangements are preferable
Distance to the household’s last-year’s swidden(s)	Shortest distance to the household’s last-year’s swiddens	Closer sites are preferable to facilitate the harvest of some non-rice cultigens and the re-use of the old swidden hut
Distance to other households’ swiddens	Shortest distance to other households’ swiddens	Closer sites are preferable to facilitate the labour exchange between households and the attempt to make clusters of swiddens to reduce the severity of pest attack.
Distance from the household’s other current swidden(s)	Shortest distance from the household’s other current swidden(s)	Farther sites are preferable to diversify the local environment among swiddens belonging to the same household.
Distance to longhouse	Distance to the longhouse	Closer sites are preferable to minimise travel time
Distance to river	Shortest distance to the river	Closer sites are preferable to minimise travel time
Topographical preference	Elevation	Sites in lower elevation are preferable

<sup>1</sup> The site index is basically calculated at the block level, thus, the site index of a plot is represented by the site index of the first block the list of blocks of a plot.

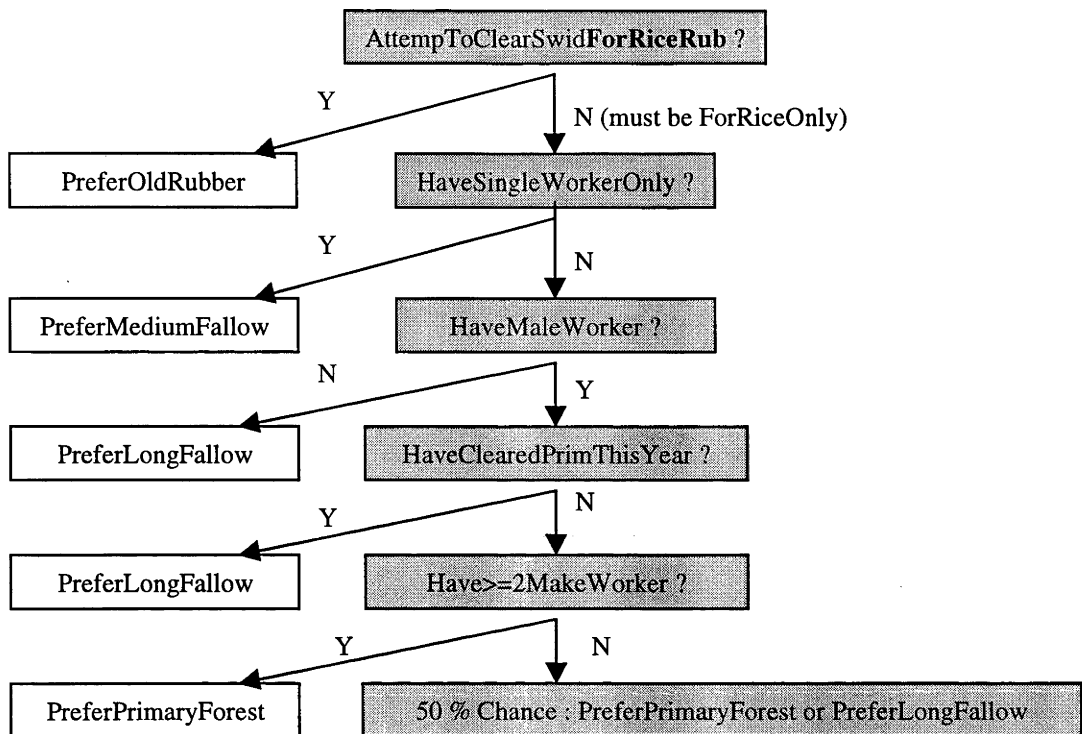


Figure 3.9 Rules for determining vegetation preference

Table 3.7 Scoring of site selection factors.

Vegetation/fallow length					
Preference	ShortFalPlot	MedFalPlot	LongFalPlot	PrimBlock	OldRubPlot
PreferPrim	1	3	4	5	excluded
PreferLongFallow	1	4	5	3	excluded
PreferMediumFallow	1	5	4	excluded	excluded
PreferOldRubber	1	2	4	3	5
Ownership					
Swidden type	Free-access	Owned	Shared	OwnByOthers	
ForRiceOnly	5	5	5	3	
ForRiceRub	5	5	excluded	excluded	
Topography					
	ElevClass1	ElevClass2	ElevClass3	ElevClass4	
Elevation	5	4	3	1	
Distance-related factors					
	Distance class (distance unit = 70.7 m)*				
Type of distance	0-7	8-18	19-32	33-50	>=50
DToLast-YearSwid	5	4	3	2	1
DToOtherHH'sSwid	5	4	3	2	1
DToLonghouse	5	4	3	2	1
DToRiver	5	4	3	2	1
DToHH'sOtherCurrSwid	1	2	3	4	5

70.7 m is the side of a block

With regards to ownership, the model takes into account the possibility of land borrowing but imposes restrictions regarding who can lend and borrow land. Only households that have five plots or less are eligible to borrow. Meanwhile, only those who can set aside more than five plots for themselves as well as for each of their junior households, with whom they share the land, are eligible to lend. The best plots, in terms of fallow duration, are reserved for the owner's use and are not lent. This rule will effectively restrict the role of land borrowing to facilitate a more equitable access to land among the land-rich and land poor households. Moreover, the restriction on the lending side is designed to ensure that the owner reserves a sufficient fallow stock to avoid short fallow rotation. On the selection process, plots that cannot be borrowed are eliminated from the list of potential sites. Among the eligible sites, free-access land, owned and shared plots are given a higher score than plots owned by others. The aforementioned rules apply only for selecting swidden for-rice-only. Rubber plots can only be established in free-access primary forest or fallow land formally owned by the household.

The model represents the topography of the landscape in a very simple way with elevation ~~is~~ the only topographical feature. Land is classified according to four elevation classes in which the numerical order corresponds to increasing elevation. In the current version of the model, areas in the lowest elevation class are located along the bank of the river. Generally, the elevation increases with distance from the river (Figure 3.4-b). Furthermore, the model assumes that sites at lower elevation are preferred over those at higher elevations. If terrain data had been available, e.g. digital data or a detailed topographic map, then this could have been used to develop a more sophisticated set of topographic factors.

For the distance-related factors, distances are classified into five non-homogeneous classes (see Table 3.7). In summary, the preference increases as the distance decreases for the following factors: distance to the household's last-year's swidden(s) and distance to other households' swiddens, distance to longhouse, distance to river. However, the



preference decreases with decreasing distance from the household's other current swidden(s).

Among the potential sites, the one with the highest site index score is converted to a swidden. If more than one such site occurs, the one closest to the longhouse is selected. If the selected site is a fallow plot, the entire plot is re-cleared. If it is a primary forest block, an attempt is made to delineate a 2-hectare plot consisting of four connected blocks. However, as more and more of the land is allocated to households this may not be achievable. When a fallow plot is not found, or four-connected blocks of primary forest cannot be established among sites having the highest score of site index, the selection process proceeds to one of two options. If the primary forest is almost all cleared (less than 25 hectares), a search is carried out for plots or blocks having the next highest site index score, otherwise the area is reduced to 1 hectare, and the selection process repeated. Therefore, there are two possible sizes of plots: one or two hectares. Once a new plot is created the link to the owner is established and this link is changed only when the ownership is transferred to another household. More discussion about this will be presented later in section 3.4.1.

#### **3.3.4.2 Setting cultivation schedule and execution of cultivation tasks**

While the model as a whole operates on a yearly basis, the execution of cultivation tasks are simulated on a daily basis. I take advantage of the individual-based approach of the model, which enables labour spending by each person to be accounted for. To do that, I use data tracking labour input and the cultivation schedule (see Table 3.2 and Figure 3.2). In short, this approach enables the 'idle' labour for each household to be identified, and this is available firstly for earning rice wages, i.e. by working on other household's swiddens and secondly is allocated to the household's labour that is available for tapping rubber.

The model sets the schedule for each plot. The timing of slashing, felling, burning, planting, weeding and harvesting are explicitly simulated to approximate the cultivation schedule of the Kantu'. The labour required for other tasks (e.g. site selection, guarding,

carrying, swidden hut making and tool making) are also accounted for but the timing of those tasks is not tracked. The timing of slashing, felling, burning, planting, weeding and harvesting are simulated randomly but constrained by the rules described shortly and the parameters presented in Table 3.8.

The model sets the burning date as the starting point to determine the entire cultivation schedule. Thus, the timings of tasks that are performed before and after burning are set by the specified interval between two successive tasks. For example, the burning date and the burning-felling interval determines the start of felling. In the model, the timing is varied slightly by using a normally distributed random function to determine the precise starting date of a particular task. As shown in Table 3.8, the statistics of the random function are prescribed using the date of the preceding or proceeding task and the interval between two successive tasks. Most of these parameters have some empirical basis but the standard deviations have been assumed. Note that due to the previously noted randomisation procedure used to determine the precise dates, the cultivation schedule among the plots will vary.

The model only prescribes the starting date for each task, and the duration to complete a task depends on the labour requirement for each task and the size of labour force of the household (Table 3.2)<sup>2</sup>. The model assumes that if a household has multiple swiddens, the workers are divided to manage different plots. Ideally, at least two workers are assigned for each plot<sup>3</sup>. The workers assigned to a particular plot are the main labour to execute the cultivation tasks for that plot. Nevertheless, the model allows the labour assigned to one plot to be used in another plot when idle.

The next event in the simulation is execution of the cultivation tasks. In this event, if workers are deemed to execute a cultivation task, they are removed from the available labour pool during the duration of execution. The starting dates of all tasks for all

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<sup>2</sup> Labour input for all cultivation tasks is calculated per hectare basis except for harvesting. The latter is calculated per kg-rice basis; one worker harvests 14.1-kg rice per day (Dove, 1985b: 319).

<sup>3</sup> Some plots may get only one worker. For example, when a household cultivates two swiddens but they only have three workers. In this case, while one plot is allocated with two workers, the other one gets only one worker.

Table 3.8 Parameters to simulate cultivation schedule

Task	Mean starting date	Standard deviation (days)	Max duration (days)	Notes
BurnPrim	20 Aug	13	2	The mean date represents the reported mean burn date of primary forest swiddens (Dove, 1985b: 139).
FellPrim	StartBurnPrim – 87	(0.1 x 87)	-	87 days is the reported average of felling-burning interval for primary forest swiddens (Dove, 1985b: 128). Note that felling-burning interval is longer in primary forest plots than secondary forest plots because these plots require a longer period to dry out.
SlashPrim	StartFellPrim – 60	7	-	Dates are arbitrarily set. Slashing of primary forest is likely to overlap with harvesting last-year's swiddens, which is already scheduled in the previous year's season. Therefore, the date selected to start slashing has to be when there is no harvesting work to be done.
PlantPrim	StartBurnPrim – 30	(0.1 x 30)	7	30 days is the desired burning-planting interval for primary forest swiddens (Dove, 1985b:146). Note that this seemingly long interval is needed in a primary forest swidden in order to dissipate the toxic residues from the burn.
HarvPrim	StartPlantPrim + 157	(0.1 x 157)	33	157 days is the reported time taken for rice to mature and 33 days is the reported maximum duration of reaping (Dove, 1985b:318-319).
BurnSec	1 Sep	20	2	The reported mean date for burning secondary forest swiddens (Dove, 1985b:139).
FellSec	StartBurnSec – 30	(0.1 x 30 )	-	30 days is an approximation to the reported average of felling-burning interval for secondary forest swiddens (Dove, 1985b:128).
SlashSec	StartFellSec - 35	(0.1 x 35)	-	Dates are arbitrarily set.
PlantSec	StartBurnSec + 7	(0.1 x 7)	7	7 days is the desired burning-planting interval for primary forest swiddens (Dove, 1985b:146). Note that the burning-planting interval is short to prevent the plot being dominated by weeds.
WeedSec	StartBurn + 42	(0.1 x 42)	56	42 days since the start of burning represents the interval when weeding can begin because the weeds are tall enough to be grasped by hand (Dove, 1985b:237).
HarvSec	StartPlantSec+ 157	(0.1 x 157)	33	See HarvPrim.

cultivated plots of a household are sorted from the earliest to the latest date. Then, task executions proceed from the earliest starting date to the latest one. When there is an overlap in the schedule, only the assigned workers execute the task in that particular plot. Otherwise, all the available workers are used to perform the task being scheduled. Thus, the duration to complete a task may vary even among the plots belonging to the same household depending on the cultivation schedule of these plots.

Some cultivation tasks are time-constrained in a sense that the task has to be completed within a specified duration. Table 3.8 presents the maximum duration for burning, planting, weeding and harvesting. If the available labour is not sufficient to complete a task within the specified duration, the household then makes a demand for external labour. Therefore, the demand for external labour is triggered by labour shortage. Likewise, the household's labour not being used is placed in a pool of labour available for hiring. Despite the range of existing mechanisms to obtain external labour (see section 3.2.6.), hiring labour is the only one simulated in this version of the model. After all the task executions are completed for each household, the model simulates labour hiring by matching the daily labour demand and supply. In this way, each household has a chance to perform wage labour. The assignment to which household a worker will work is a purely random event. When the demand is greater the supply, it is assumed that labour from outside the village is hired. Wages for labour are paid by rice at the rate of 3.5 kg (unhusked rice)/worker/day (Dove, 1984:115). The model tracks the amount of rice paid for wages as well as the rice earned.

### **3.3.5 Production evaluation module**

Although the rice and cash production in this model is targeted to fulfil the household's demand, a range of factors could result in the targeted production not being met. The production evaluation module assesses the sufficiency of the available rice and cash to meet the demands for each household. Firstly, the rice sufficiency to various components of demand is evaluated. The model simulates cash (rubber) production after the rice sufficiency has been evaluated. This enables the model to simulate an

intensified rubber production for households experiencing rice shortage. This procedure reflects the role of rubber for Kantu' as a 'cushion' in the event of economic misfortune such as harvest failure (see Dove, 1993). Apart from tapping the household's own rubber plots, the model allows tapping rubber from other households' plots carried out in a share tapping arrangement. Following rubber production, cash sufficiency is evaluated. For households who cannot meet the entire cash or rice demand, a procedure is in place to simulate rice/cash borrowing from surplus households.

The details of processes in the production evaluation module are explained with reference to the rules described in Figure 3.10, which summarises the general flow of events in this module. First note that at any one-year, the rice currently available (CurrRice) consists of the rice produced from the last-year's swiddens, rice stored as a result of surplus from previous years and rice earned as wages. The model then has to decide how the available rice is to be spent for various components of rice demand. Recall that the model distinguishes several types of rice demand. The rice demand for eating, seed and paying wages constitutes the annual rice demand (AnnRiceDmd). The annual rice demand plus the rice debt constitutes the total rice demand (TotRiceDmd). A failure to meet the entire annual rice demand (RiceMinus) as well as rice debts puts additional demand to the annual cash demand for buying rice. However, spending rice to fulfil the annual rice demand is given priority over paying rice debt. The model establishes a link between the rice/cash lender and borrower. Thus, every time a debt payment is made, the debt record on both sides is updated. Note that none of the households sell rice. The rice surplus is stored and this rice can be borrowed by other households. The market for rice is assumed to be from outside the village. The model evaluates rice sufficiency for all households before proceeding to simulate the rubber production.

The production of rubber is targeted to fulfil the total cash demand (TotCashDmd), which consists of annual cash demand (AnnCashDmd), additional cash demand to buy rice and, paying rice or cash debt. The annual cash demand refers to the sum of per-

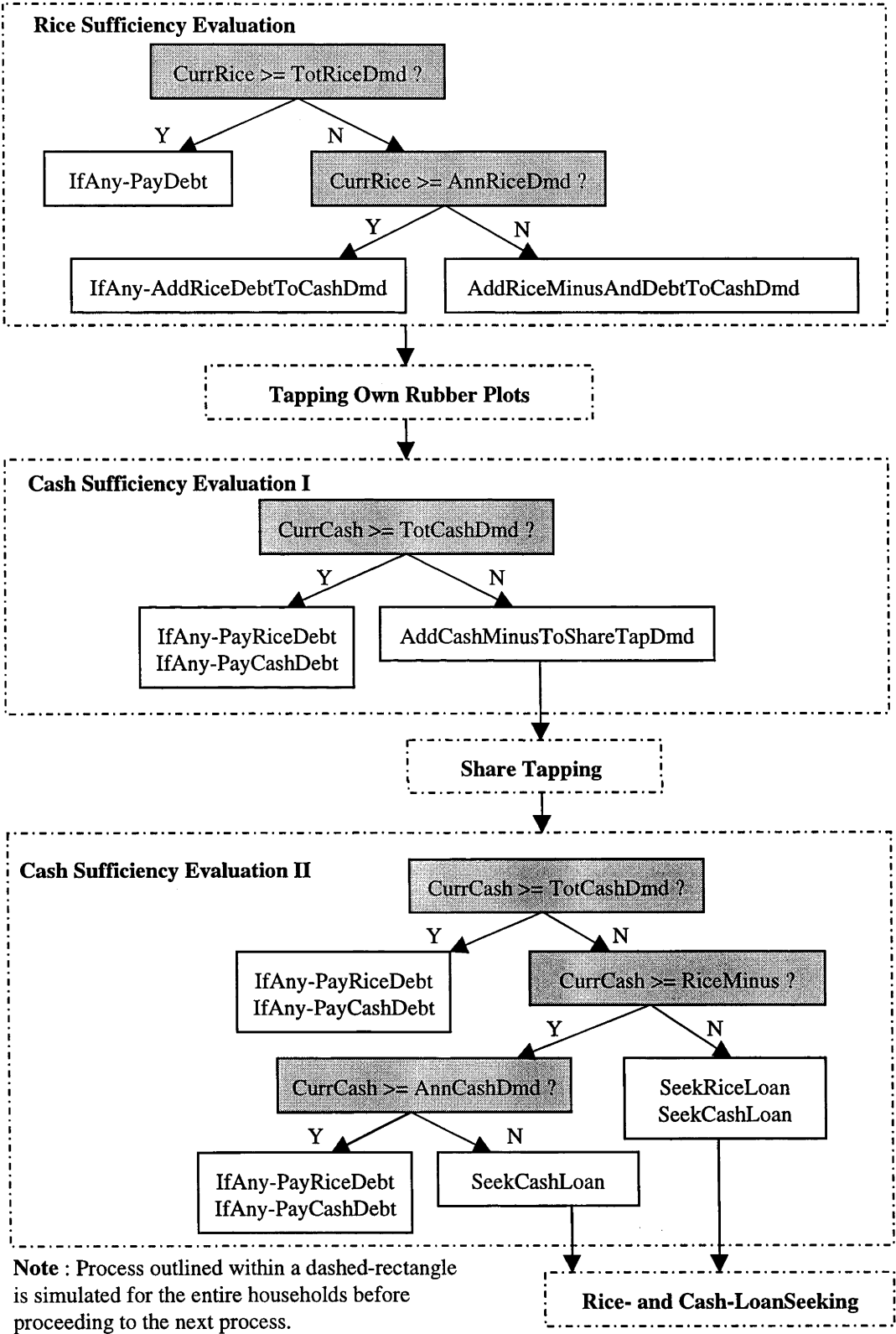


Figure 3.10 Main flow of events in the production evaluation module

capita cash requirement for all members of the household. Per-capita cash requirement is derived from the value of annual consumption of basic goods (i.e. sugar, rice, textile, salt, kerosene and cooking oil). Table 3.9 outlines the calculation to derive the value of this parameter as well as the price for rubber and rice. Tapping is carried out by males and females (Drake, 1982:109). Tapping is simulated per worker per 0.5 ha rubber block on a daily basis. The model assumes a low rubber productivity where the production from mature and old rubber plots is 2.0 and 1.0 kg/day/worker/0.5 ha respectively<sup>4</sup>. The model specifies that the maximum tapping days for each rubber block is 180 days/year, which is based on the official guidance for smallholders in Sarawak (Lian, 1987:1957)<sup>5</sup>.

It is assumed that the market can purchase all the rubber that is produced. Furthermore, rubber tapping is carried out during the idle periods of swidden works, but the exact timing is not specifically set. During these periods, the available workers tap rubber daily until the monetary value of the production exceeds the demanded cash or there are no more tappable (mature and old) rubber plots available. In other words, the rubber production of a household could be constrained by the availability of workers and/or tappable plots. A share tapping arrangement is in place to extend the access to other household's tappable plots. In reality, share tapping is a common practice. The share tapping arrangement in this model specifies an equal share of the production between the tapper and the owner, as reported for the Mualang (Drake, 1982:146) and Iban (Freeman, 1992:269).

The model assumes that households prefer to tap their own rubber plot instead of share tapping. Share tapping is only done when the total cash demand is met. The model simulates tapping own rubber for entire households before proceeding to share tapping.

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<sup>4</sup> The assumption on low rubber productivity is based from Dove (1993:139) and Drake (1982:143). Nevertheless, higher estimates of rubber production have also been reported (e.g. Barlow and Muharminto, 1982:102; Wadley, 1997a:103).

<sup>5</sup> Under the current set of assumptions, the 'potential' (mature) rubber production is 720 kg/ha/yea, which is higher than the reported figure for Indonesian smallholders (525 kg/ha/year) but lower than that for rubber estates (1,186 kg/ha/year) (Barlow and Tomich, 1991:34).

Table 3.9 Per-capita consumption and prices for selected basic goods.

Items	Per-capita annual Consumption <sup>1</sup>	Price/Unit (Rp) <sup>2</sup>	Value/ Per-capita (Rp)
Sugar (kg)	12	260	3119
Textile (m)	10	257	2573
Salt (kg)	3.24	97	313
Kerosene (lt)	48	69	3300
Cooking oil (lt)	4.8	492	2361
			<b>11,665</b>
Rice (kg of milled rice) <sup>3</sup>	-	165	
Rubber (kg)	-	160	

**Notes:**

<sup>1</sup> Data for West Kalimantan province, 1980. Source: Statistics Office of West Kalimantan (1980).

<sup>2</sup> All prices refer to the 1978 price for Putussibau, the capital city of Kapuas Hulu regency. Sources: Statistics Office of West Kalimantan (1978, 1980).

<sup>3</sup> Rice measurement in the model is always presented in the form of unhusked rice. The equivalent price for unhusked rice is estimated as 50 per cent of the price of milled rice that based on an estimate of the weight reduction after the rice is milled.

This ensures that the rubber plots available for share tapping are the ones that are no longer needed by the owners. Moreover, if the combined proceeds of tapping own rubber and share tapping are still not enough to cover the total cash demand, the priority of money allocation is firstly to buy the deficit rice and then to cover the annual cash demand for buying basic goods. If these two types of demand are not met, a loan will be sought and the household is put on the loan-seeking list. Note that the failure to pay previous debt does not trigger new loan seeking. As in the share tapping, the loan-seeking process is conducted at this stage so that those with rice or cash surplus are known with certainty. The model simulates the loan-seeking process by randomly matching needy and surplus households. A household will lend rice or cash if the amount of surplus exceeds the amount required by a needy household. Lastly, any cash surplus is used to pay debts, if any. When debt is in rice form, the monetary value is converted to the equivalent rice mass.



To conclude this section, note that the model sets the commodity prices at 1978 prices throughout the simulation. In Chapter 5, I will present a modified version that relaxes the fixed price assumption.

### **3.4 Exploring the behaviour of the land-use model**

This section examines some selected behaviours of the model, which is intended to demonstrate the implications of the assumptions described in the previous sections. It also serves another purpose, that is, to check whether the assumptions have been correctly implemented in the model. The analysis is based on the dynamics of a household in a single run. The first part of this section will discuss the process of swidden selection and the geographical distribution of potential sites as evaluated by the site index. What follows is a discussion on the dynamics of selected variables capturing the essential household states with regards to the structure and composition, type of clearing, land holding accumulation, and the accounts of production and expenditure for rice and cash. Both analyses focus on one arbitrarily selected household whose history is monitored for 75 years. It is important to note that the dynamics of each household varies enormously and the details of the household shown in this section is by no means typical. To facilitate explanation, the household under investigation is called 'household-A'.

#### **3.4.1 Process of site selection**

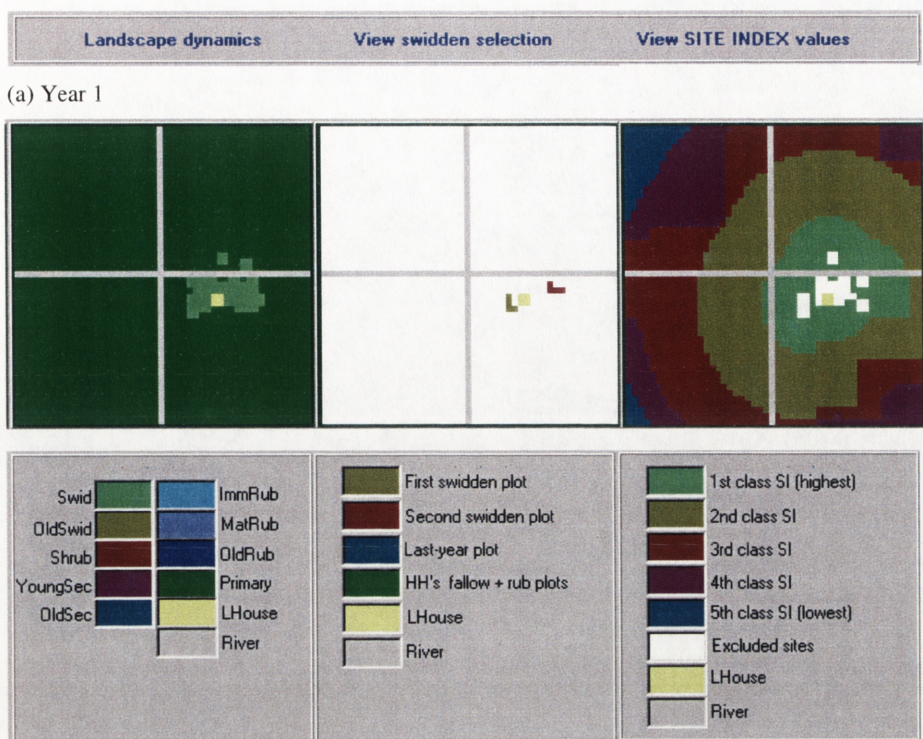
The model evaluates the attractiveness of potential sites for swiddens using a site index (Table 3.4). It is important to note that the geographical distribution of potential sites is unique for each household as the site index contains selection factors which are household specific, such as distance to the household's last-year's swidden or from the household's other current swidden. It is also unique for each year since the previous land-use decisions made by households means that that selection index is continually changing.

In order to illustrate the process of swidden selection snapshots of a series of simulated maps are presented in Figure 3.11. Each panel consists of three simulated maps. The

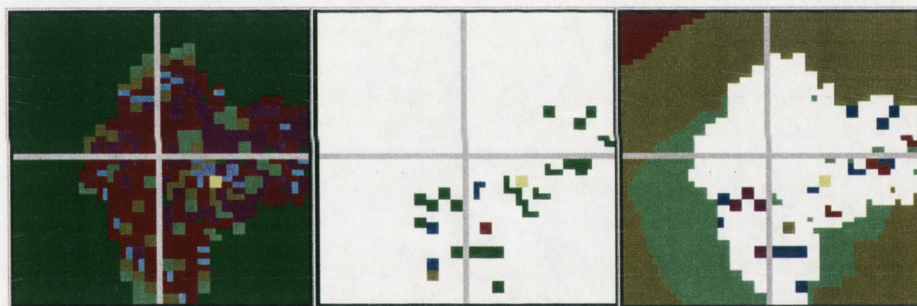
first map (left) presents the vegetation composition of the landscape as a result of land-use decisions made by the entire community. The second map (middle) shows the location of the household's current swiddens in relation to the previously acquired plots. Note that as a household may cultivate more than one swidden in a year the map marks the first and second selected swidden separately. The third map (right) shows the geographical distribution of site index values for the selection of the swidden plot, and unless mentioned, it refers specifically to the 'first' swidden plot. To summarise the degree of attractiveness, the site index values are classified into five classes. The classification is based on the highest and lowest site index values for each year. The interval between successive classes is calculated from the difference between these extreme values divided by five. Another important feature is the excluded sites, which consist of the current-year swidden, last-year's swidden, immature rubber and mature rubber plots of all households, and plots belonging to other households that are not available for sharing and borrowing arrangement.

The distribution of site index values in the first year of simulation is presented in Figure 3.11-a. This figure can be used to check the plausibility of the site index values in relation to the 'un-moving' benchmarks, i.e. distance to the longhouse, to the river and topography, since at the beginning of the simulation, there is mostly primary forest, and the other factors do not yet exert a significant influence in determining the site index values. Figure 3.11-a shows the expected pattern; the highest values reside in locations that are in the closest proximity to the longhouse and river as well as in the lowest elevation class (see Figure 3.4-b for the topography). As a further check, note that the location of the first swidden (in the second map) falls within the area of the first class of site index (in the third map). Although most of the selected swiddens would be those with the highest site index value, there are some circumstances where they do not. For example, one situation that can trigger this is when the sites with the highest site index consists entirely of primary forest blocks but the household fails to delineate the specified number of connected primary forest blocks in each potential site.





(b) Year 15, selection of first swidden (right)



(c) Year 15, selection of second swidden (right)

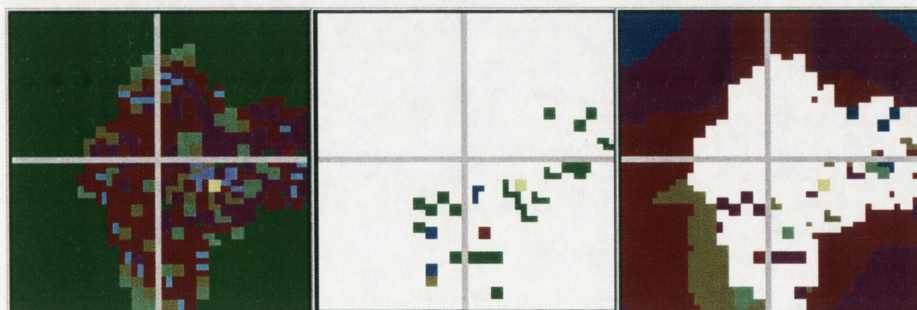


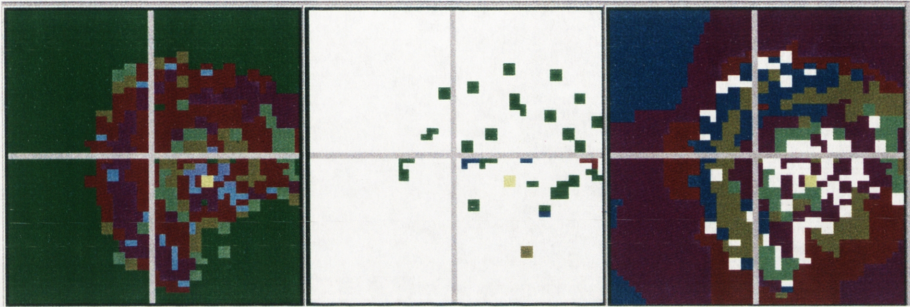
Figure 3.11 Process of site selection. In each panel, left, middle and right map refer to vegetation composition of the entire landscape, plots owned by the household and distribution of site index values, respectively.



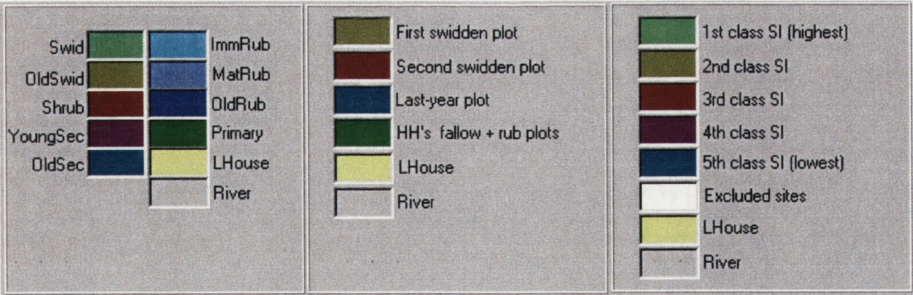
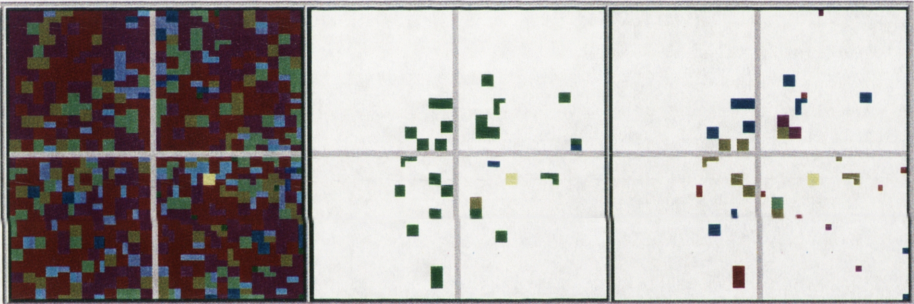
Continuation of Figure 3.11



(d) Year 15, constraint of ownership is lifted



(e) Year 50



As explained in section 3.3.4.1, there are two possible options in this situation, decreasing the attempted plot size to 1 hectare (two blocks) or to move the search to the sites with next highest site index value. The first option is taken when the primary forest is almost finished (less than 25 hectares), but in other cases the second option is taken. This rule tries to maximise the chance of creating 2-hectare plots which is the average swidden size reported for the Kantu'. An examination from a single run reveals that this rule, which essentially postpones the formation of 1-hectare plots, does in fact maximise the formation of 2-hectare plots because about 69 % of all plots are 2 hectares. Without the rule, the proportion drops to 21 %. However, some 1-hectare plots do exist in the early years, and they are formed through plot division following the planting of swidden for rice and rubber in which 1-hectare part of a 2-hectare plot is converted to a rubber plot.

The second map (Figure 3.11-b) shows that after 15 years, the household-A have acquired a large number of plots which spread all over the territory. Note that the potential sites having the highest site index values have shifted to areas a considerable distance from the longhouse but within the area of primary forest (cf. Fig 3.11-a and 3.11-b). By looking at the location of the first swidden, it appears that this first swidden is selected mainly due to the type of vegetation (primary forest), ownership (free-access), and the close proximity to the last-year's swidden and to the river. A different view can be seen when we look at the distribution of site index values for selection of the second swidden presented in Figure 3.11-c. The area of primary forest is no longer the most attractive, indicating that the intention for this particular event is to clear a fallow plot. Note that given the high weight of the vegetation factor, the selected second swidden is likely to be a long fallow plot (aged  $\geq 10$  years).

Furthermore, by looking at the magnitude of excluded sites in Figure 3.11-b, it can be seen that almost half of the territory is not available for the household-A by year 15. These excluded sites include current-year swidden, last-year's swidden, immature rubber and mature rubber plots of all households, and plots belonging to other

households<sup>6</sup>. Recall that although the model allows land borrowing, the best sites are usually reserved for the owner and are not available for lending. It is useful to know to what degree this ownership factor constrains the availability of potential sites. One way to assess this is by removing this constraint to ownership and then assessing the differences. The modification has been carried out, for the illustrative purpose only, by taking the ownership factor out from the site index. The result from this modified version is presented Figure 3.11-d, which shows a significant increase in the number of available plots when the ownership is not a constraint. As would be expected, the ownership constraint becomes increasingly dominant as the number of households increases, and at year 50 the potential sites are largely confined to the household's owned plots (Fig. 3.11-e).

### 3.4.2 Dynamics of selected important household's states

Figure 3-12 summarises the internal dynamics of the household-A over time. Demographic changes (Figure 3.12-a) result from birth, death, marriage and partition events. Marriage and partition are particularly crucial since they involve changes in the labour force. Departure of a household member due to death or out-marriage is generally shown as the slight decrease in the number of members. However, the sharper reduction in number of members results from household partition. The household-A has undergone partition on six times (Fig. 3.12-a) occurring at year 8, 11, 13, 18, 19 and 55 and, for the sake of convenience, the resulting 'junior' households are called household-B, -C, -D, -E and -F respectively. The first five junior households are formed by children of the household's founder (2<sup>nd</sup> generation), while the last junior household is formed by a grandchild (3<sup>rd</sup> generation). The implications of these partitions are discussed later.

Figure 3.12-b demonstrates that the model successfully reflects one of the core assumptions, that is, the attempt by each household to combine clearing primary and secondary (fallow) plots each year. Generally, only one primary forest plot is cleared

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<sup>6</sup> In a situation where a household has only one worker, primary forest plots are also excluded (see Figure 3.9).



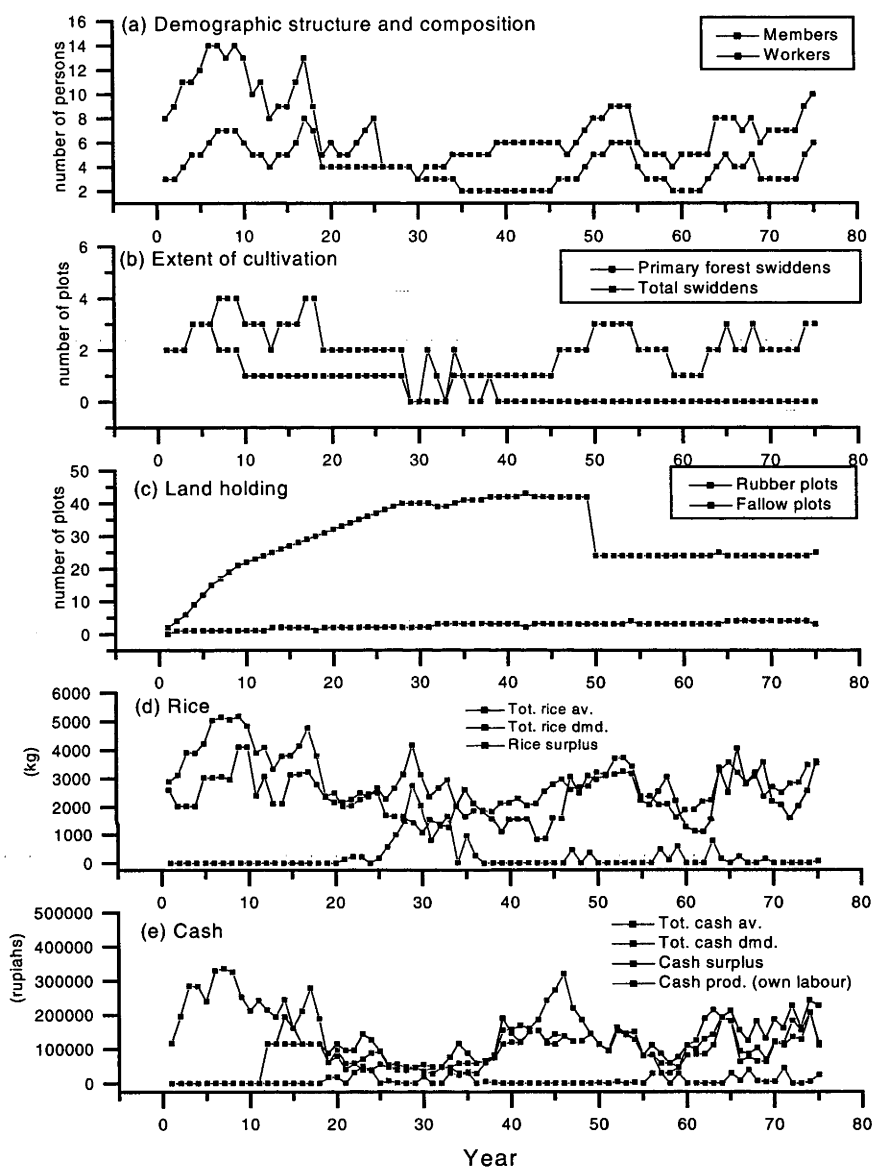


Figure 3.12 Dynamics of selected important household's states

each year except in the first five years when the secondary plots with sufficient fallow length are not yet available or when the number of workers is large. As a result of continuous clearing of primary forest, the land holding accumulates rapidly, which reaches 42 plots by year 38 (Figure 3.12-c). Absence of primary forest clearing from year 40 onwards is because there is no primary forest left (Fig. 3.11). Up to year 50, the 'senior' household-A shares the fallow plots with the junior household -B, -C, -D and -E. The land inheritance occurs at year 50 and it is triggered by a partition occurring at the junior 'household-B' (i.e. the second type of timing according to Figure 3.6-b). The size of the land holding drops sharply after land inheritance. An examination on the plot division of this particular household reveals that 55 % of the plots remains under the ownership of the household. The rest are given away to the junior households-B, -C, -D and -E, where each of them receives between three to five plots. This apparent unbalanced land division is as a consequence of the rules of land inheritance (section 3.3.3.1), would give the successor a higher chance to obtain a larger proportion than the others. Following this land inheritance, household-B, -C, -D and -E are no longer entitled to use the plots of household-A under the land sharing arrangement but they may 'borrow' these plots. The remaining plots are the portion allotted for the successor of household-A and these plots are later to be shared with the junior household-F, which is formed by a child of the household-A's successor.

As expected, the level of rice demand (Figure 3.12-d) generally corresponds with the structure and composition of the household (Figure 3.12-a). There<sup>are</sup> occasions when the household-A does not cultivate swidden (year 29, 30 and 33). This is because the accumulated rice surplus (Figure 3.12-d) is so abundant that, as specified by the model, no cultivation is carried out on those years. This particular rule is used to prevent an unrealistic accumulation of rice surplus. An examination of the proportion of the various components of rice demand (section 3.3.5) reveals that for this particular household, eating rice constitutes the largest part; it amounts to on average, about 90 % of the total rice demand throughout the simulation. Meanwhile, most of the total rice available comes from the last-year's harvest, which amounts to an average of about 90 %. These



data suggest a relatively minor role of rice earned as wages in the household's annual rice expenditure.

Nevertheless, one might question why an accumulation of rice occurs given the assumption that the level of production is targeted to fulfil the current demand only. The main reason seems to reside in the way in which the extent of cultivation is simulated. Recall the steps to determine the extent of cultivation as summarised in Figure 3.8 presented earlier. Each time a new swidden is selected, the model estimates the amount of expected rice production. The addition of a new swidden will cease when the expected rice production exceeds the total demand. However, a household will continue adding a new swidden even if the accumulated rice is only a few kilograms less than the total demand. In this case, the expected total harvest could well exceed the demanded amount, thus resulting in rice surplus. Note that the rice surplus carried from the previous year does not affect the level of demand for the current year; the household continues to put a new rice demand proportional to the current consumption requirement. If the conditions leading to the rice surplus are repeated for several consecutive years, the end result could be a large accumulation of rice surplus. To prevent an unrealistic accumulation of rice, the model enforces a rule that does not allow a household to cultivate swidden when the amount of accumulated rice surplus is twice or more than the total rice demand.

In terms of cash production and expenditure, first recall that apart from the amount required for buying basic goods, rice shortage will <sup>create</sup> ~~put~~ additional cash demand for buying market rice. As can be seen in Figure 3.12-e, the occasions of relatively high cash demand occur when the total rice available is less than the total rice demand (e.g. year 45). In most cases, the total cash available can fulfill the cash demand except in the first 15 years, when most of rubber plots are not yet in production. Note that there is no significant cash accumulation. The reason is that the cash surplus carried from the previous year is taken into account in setting the level of rubber production in the sense that it is targeted to fulfill only the part of the total demand that is not covered by the cash surplus. The sources of cash surplus are payment from share-tapping arrangements

and payment from cash loans. The other reason is that, unlike in swidden cultivation, the rubber tapping is simulated on a daily basis. In this case, once the monetary value of the accumulated production is equivalent to the demanded cash, the tapping ceases.

### 3.5 Conclusion

This chapter has shown that the individual-based approach enables a considerable amount of the detail about the Kantu's 'life', particularly that which directly or indirectly affects land-use, to be simulated; e.g. the marriage system, the land inheritance system and even the 'cash flow' of households. In this way, the model is able to link the social-cultural system to the land-use system, which is one of the major achievements of this study. This connection provides an avenue to capture phenomena that are not explicitly addressed in the existing land-use models; among them are the process of land acquisition and inheritance. Land inheritance in particular has a crucial function as a means to distribute the land resource across generations. Representing the community as a collection of individual persons organised into households is the key to the simulation of land inheritance. It is interesting to note that more than 35 years ago (Kunstadter *et al.*, 1963), who developed one of the earliest individual-based models for use with human population, did mention the future applicability of this approach to simulate inheritance. However, to my knowledge, no other modelling studies have tackled this issue since, especially in the land-use context.

In the following chapter the model is used to analyse the dynamics of the swidden cultivation system of the Kantu'.

## **Chapter 4**

### **Analysing the Swidden Cultivation of the Kantu': Land-Use Simulation Results**

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#### **4.1 Introduction**

This chapter will present the dynamics of swidden cultivation of the Kantu', which is simulated using the land-use model described in Chapter 3. The fundamental assumption in this model is that the level of agricultural production of rice and rubber is geared to fulfil the 'subsistence' demand, with land and labour as the chief means of production. The aim of this chapter is, firstly, to investigate the role of land tenure and the inheritance system in affecting households' access to land and its implications for the fallowing practice. Secondly, the chapter investigates the intensity of labour use and the role of demographic structure of the household in constraining agricultural production. And finally, the chapter asks to what extent the land and labour available at households' disposal can produce the demanded rice and cash.

The land-use model is run for 75 years and the analysis is based on trends resulting from the average of 20 multiple runs, unless stated. In addition, comparisons with a 'modified' version are carried out to investigate the role of post-marital residence in affecting the access to land. The results will also be compared with empirical data when such data are available.

#### **4.2 Population pressure**

In this version of the model, population growth is the only pressure on the swidden cultivation system. To illustrate the magnitude of population pressure, the simulated population increases from 63 to 421 persons with the number of household increases from 9 to 80. Note that when the model is run in population-only mode (Chapter 2), the post-marital residence rule is based on the membership status and number of siblings eligible for inheritance (see section 2.3.4). This rule is modified in the land-use model (see section 3.3.3.2); as apart from the membership status, the size of land

holding is taken into account. As expected, this modification generally does not affect the outcome; the annual rate of growth throughout the simulation period in both the population-only and the land-use mode is 2.6 %.

Population pressure may also be presented in relation to arable land (excluding river and longhouse) or population density. Given about 12 km<sup>2</sup> of arable land, the population density increases from around 5 to 36 persons per km<sup>2</sup> (Figure 4.1), which encompasses the range of density where swidden cultivation in a ‘traditional form’ has been reported in Kalimantan/Borneo (Table 4.1). The simulation ends at a higher density than those reported figures, which implies that the situation at the final year represents a very high pressure on the land.

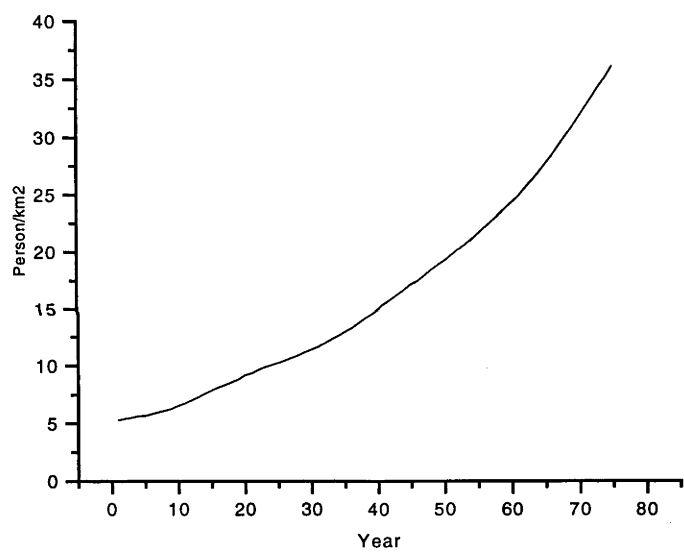


Figure 4.1 Population density of the simulated landscape

Table 4.1 Population density of selected swidden cultivation communities.

Location	Density (persons/km2)	Reference
Tikul Batu, West Kalimantan	11.5	Dove (1981:94)
Batu Lintang and Nanga Tapih, Sarawak	13.8 and 21.6	Cramb (1993:215)
Wong Garai, West Kalimantan	4.1	Wadley (1997a:35)
Kembera, West Kalimantan	14	Lawrence (1998:137)

### **4.3 Pattern of the agricultural expansion and its implications on the landscape**

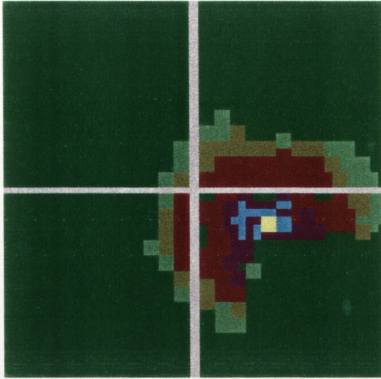
Apart from population growth, the extent of swidden cultivation of each household and the preference perceived by each household concerning the ‘best’ location of the swiddens are the other main factors that determine the pattern of agricultural expansion over the period. The simulation result shows that the average number of swiddens per household range from 1.4 to 2.6 over the entire simulation period with the corresponding area ranging from 2.5 to 5.2 hectare per household. This compares with a figure for the Kantu’ which shows that each household made on average 2.3 swiddens with the corresponding area of 4.6 hectares (Dove, 1981). The fact that the simulated values encompass those of the empirical ones indicates that the model is able to present a more or less realistic rate of agricultural expansion.

The pattern of agricultural expansion is firstly illustrated by the spatial pattern of the landscape at several ‘snapshots’ from a single run (Figure 4.2). This resulting landscape mosaic reflects the consequences of farmers’ preferences in locating the swiddens and rubber groves, which is simulated as a function of vegetation type, ownership and spatial factors (topography and distance). The figure shows that the agricultural expansion starts from the area surrounding the longhouse and extends outward with the area in the lowest topography (see Figure 3.4-b for the topographic feature) and nearest to the river cleared first. The pattern of swidden clearing shows a tendency of several swiddens to form clusters, which results from the farmers’ preference to locate new swiddens adjacent to the swidden of other households. Likewise, recurrent adjacency of current swiddens to ‘old swiddens’ reflects the preference of choosing sites near last-year’s swiddens.

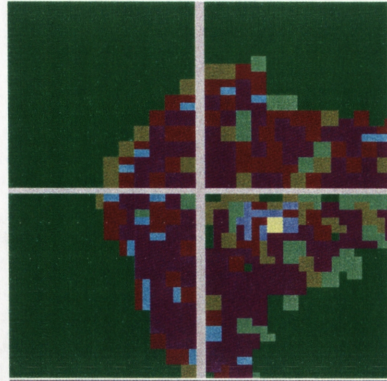
Figure 4.3-a and 4.3-b present some measures of agricultural expansion and landscape dynamics based on the average of multiple runs. In any one year, swiddens or groups of swiddens are spread all over the village territory. While clearing of primary forest for swiddens continues on all fronts of the primary forest edge, some swiddens are made in secondary forest plots. The expansion into primary



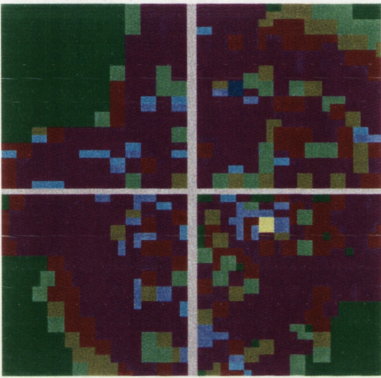
Year 5



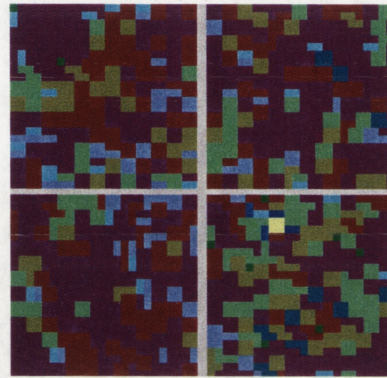
Year 15



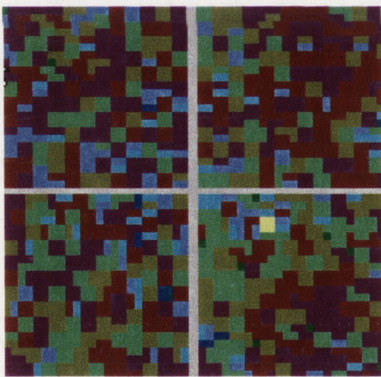
Year 30



Year 45



Year 60



Year 75

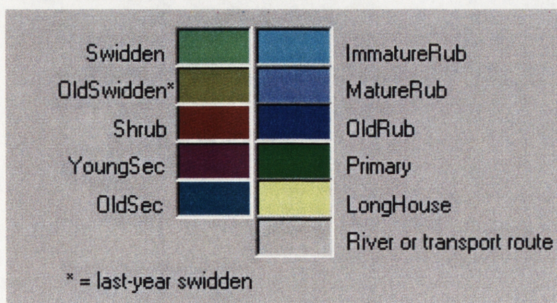
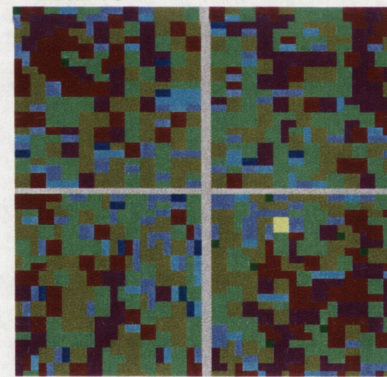


Figure 4.2 A ‘snapshot’ of the landscape from a single run to illustrate the pattern of agriculture expansion.

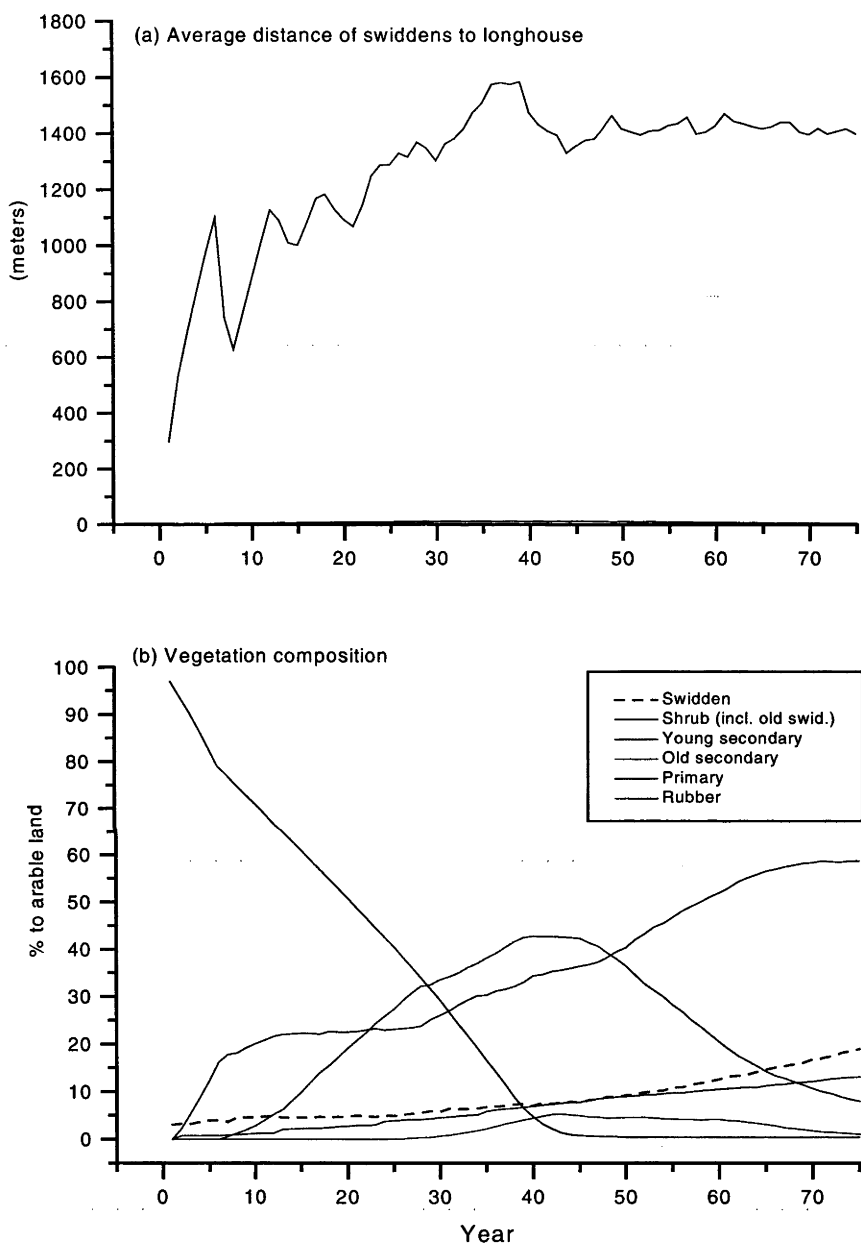


Figure 4.3 Distance of swiddens to the longhouse and vegetation composition of the landscape

forest is fast during the first five years since no desirable fallow plots are yet available, which can be seen from the sharp increase in the average swidden distance to the longhouse shown in Figure 4.3-a. Following this initial increase, the average distance drops as a result of a 'synchronous' return to the medium or long fallow plots, while some swiddens continue to be made in primary forest<sup>1</sup>. The periodic and synchronous return to the fallow plots results in a regular oscillation in the average distance during the first 30 years. After that, as the number of household increases, so does the variation in the clearing history among the households. The variation is such that eventually the periodic return no longer produces a distinct pattern as far as the distance to the longhouse is concerned. At this time the average distance stabilises at around 1.4 km.

The changes in vegetation composition throughout the simulation period are presented in Figure 4.3-b. To explain the dynamics, first note that the extent of each vegetation type in any one year is a function of the rate of land clearing and vegetation succession. With the current assumptions about agricultural decision-making, primary forest decreases at an average rate of around 25 ha/year and virtually disappears after 45 years. This is very close to what happened in reality. During my visit (in 1999, which would be comparable to year 40-45 of the simulation), the Kantu' told me that the primary forest had finished. Furthermore, soon after the desirable fallow plots are available, households combine making swiddens in primary forest and fallow plots. Nevertheless, the rate of fallow land conversion into swiddens is lower than the rate of fallow land formation because primary forest is still preferred for clearing in some circumstances. Consequently, the shrub and eventually young secondary forest accumulate. Old secondary forest starts to appear after 25 years or so from the initial primary forest clearing, nevertheless, the extent of old secondary forest is generally small. After all primary forest is cleared, the stock of young secondary forest rapidly diminishes since all swiddens now have to be made in fallow land. In addition, the young secondary forest is cleared first since it is the most preferred vegetation. As the population grows, the area of swiddens continues to increase and consequently so does the

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<sup>1</sup> The average distance would have fallen further if all swiddens were made in fallow plots.



shrubland, which is formed following the abandonment of swiddens. At the end of the simulation, shrubland dominates the landscape.

## **4.4 Access to land and its implications for fallowing practice**

### **4.4.1 Land holding distribution**

There are two mechanisms by which households acquire ownership to land: firstly by clearing and making swidden in primary forest and secondly by inheriting land from a parent. We can distinguish two critical periods in the development of a community that determines the distribution of fallow land holding. The first period is before the disappearance of primary forest. Although land inheritance may also occur in some households, clearing primary forest is the main means to acquire land during this period. Since clearing primary forest requires the presence of at least one male worker, the distribution of land holding is largely a function of the age of household and the continuing presence of male workers. Households that are established earlier and with male workers simply have more chance to accumulate plots. The rate of land accumulation is especially high in the nine initial households; the average land holding among these initial households after 20 years is 26 plots. This simulated figure is slightly less than the average rate of land accumulation among the pioneering Kantu' households after 20 years since the first territorial occupation, which was 31 plots (Dove, 1985b:79).

The second period occurs after all primary forest has been cleared during which land inheritance is the only mechanism to acquire land. During this period, land acquired through inheritance depends on the size of the parents' land holding and the number of eligible siblings and the duration of residence in the parents' household. Households with a history of high frequency of in-marriage will have a larger number of eligible children and therefore a smaller land inheritance for each child.

The longitudinal trend on land holding distribution is presented in Figure 4.4-a . Before discussing the pattern further, it should be borne in mind that due to the time lag between household formation and land inheritance, there are always groups of senior and junior households sharing the land. Therefore, the size of 'formal' land holding only partially reflects the access of land. The access to land for senior

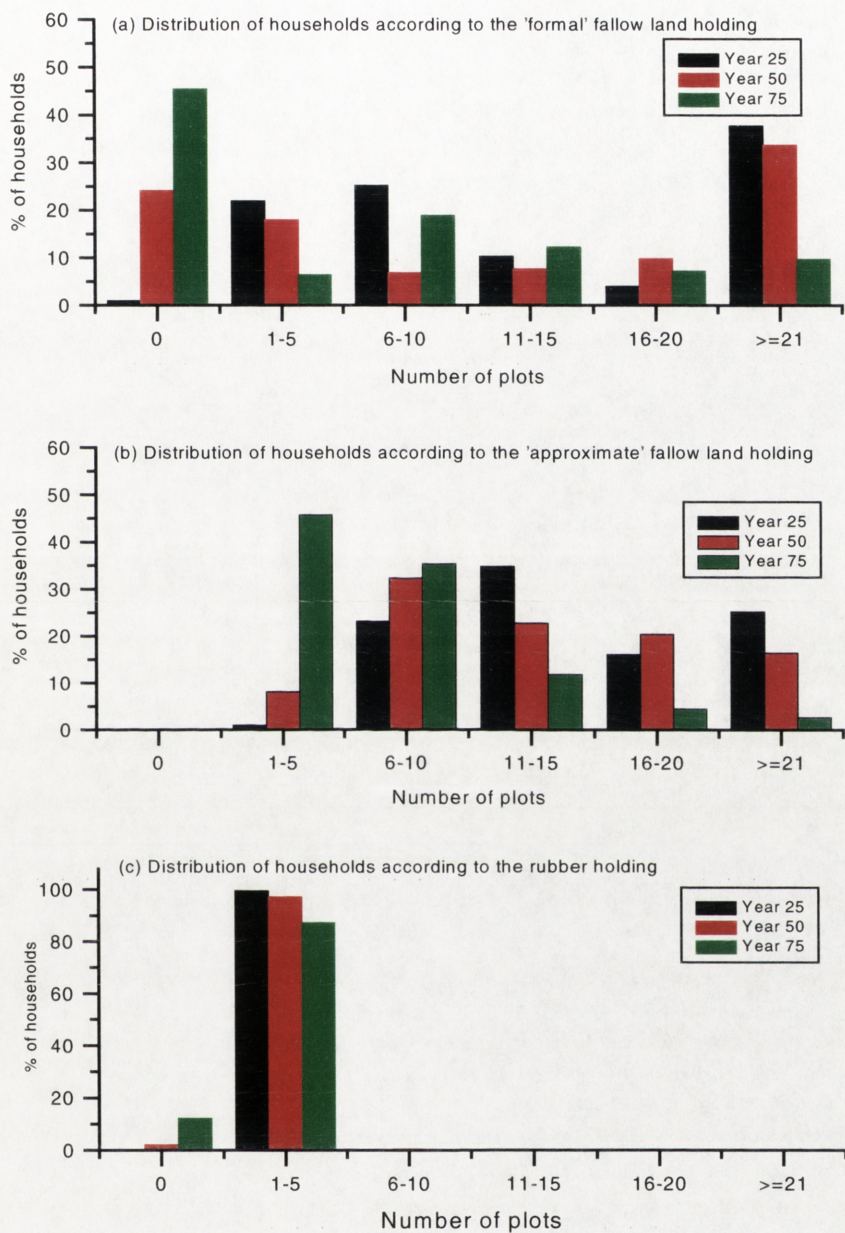


Figure 4.4 Distribution of fallow land holding and rubber land holding.

households is always less than what they formally hold since some of the land may not be available because of being used by the junior households. Similarly, junior households may formally hold no land. However, it does not mean that these households have no access to land since they are entitled to use senior households' land. During the simulation, the proportion of households in the sharing land arrangement is high, amounting on average to 70 % each year. Therefore, a better assessment of households' access to land would need to take into account the number of junior households with which holdings are shared. For this purpose, the variable 'approximate' land holding is used as a proxy for households' access to land. As mentioned in section 3.3.3.2, this variable represents the approximate number of plots that each household would acquire if the land inheritance happened at any one year.

The pattern of the approximate land holding distribution presented in Figure 4.4-b suggests a noticeable differentiation on the households' access to land. The presence of households with approximate land holding of five plots or less is particularly important since these households are likely to practice short fallow rotation. The number of households belonging in this land holding group increases dramatically during the last 25 years reflecting a severe land shortage due to the population pressure. It is interesting to note that even when the population pressure is at its highest level (at the end of the simulation), there are few households (about 6 %) that are well endowed with land (> 15 plots).

Meanwhile, the distribution of rubber holding is presented in Figure 4.4-c. The low intensity of rubber planting assumed by the model results in a relatively uniform rubber holding with most households owning one to five plots. In comparison, Dove (1993:138) reported that each Kantu' household owned an average of five rubber plots at 1976. Despite the assumed intention to have at least one rubber plot (see Figure 3.8), some households fail to do so, because these households have no fallow plots to be converted into rubber<sup>2</sup>.

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<sup>2</sup> The model assumes that planting rubber is pursued only when households have at least two fallow plots.

The distribution of fallow land holding in particular is a reflection of the demographic forces underlying the household proliferation in which marriage and particularly decisions on post-marital residences are the crucial elements. In this model, the size of household's land holding is taken into account in deciding the post-marital residence; the person from the household with the smaller number of plots moves to the larger one. This rule should theoretically exert a degree of equalising effect by giving higher chance of in-marriage in households with larger land holding, thus lessen the chance of continuing accumulation of the land. However, given the interactions and random nature of the simulation, it is rather difficult to trace to what extent land distribution can be attributed to the equalising effect of the post-marital residence rule. This question can be investigated by comparing this result with the one produced from a simulation mode that imposes a random decision on residence, hereafter called 'random residence mode', in which *virilocal* is given the same chance as *uxirilocal* residence regardless of the land holding size of both sides.

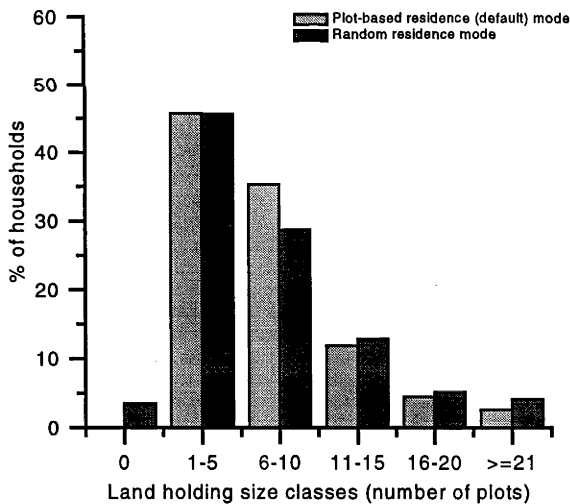


Figure 4.5 Effect of different rules of post-marital residence on the approximate distribution of fallow land holding. In the plot-based residence mode, the size of land holding is taken into account in the decision, while in random mode the chance for virilocal and uxirilocal residence is equal.



The comparison presented in Figure 4.5 suggests a minor equalising effect of the plot-based residence rule; it brings about a lesser proportion of households in the zero holding class. The plot-based residence rule also results in smaller proportion of households in extremely large holding classes ( $\geq 16$ ) but the difference is small. However, the difference in the land holding distribution between two modes is not statistically significant according to the Kolmogorov-Smirnov test (at  $\alpha = 0.01$ ). This suggests that the similarity in the occurrence of few large land-holding households in both simulation modes is more telling than the subtle difference between them. This presumably indicates that, even under increasing population pressure, random chance alone could facilitate the persistence of a few large land-holding households. However, it should be borne in mind that the size of land holding is taken into account only for deciding the residence of marrying persons but not for selecting the spouse, which is solely based on the age difference. This issue will be not dealt in this study, nevertheless, introducing consideration of wealth (land holding) in the ‘marriage matching’ process and exploring its implications on land distribution using this modeling framework would itself be an interesting research exercise that is worth pursuing in the future.

Although the magnitude may not be the same, the emergence of land inequality has been reported in many swidden cultivation communities, including the Kantu’ (e.g. Coomes *et al.*, 2000; Cramb, 1989a; Dove, 1985b; Padoch, 1982). Padoch (1982:45) in particular highlighted the role of demographic factors, i.e. differing birth, death, household fission and fusion that results in differences in the amount of land owned. Some degree of land inequality was also observed during my recent visit to the Kantu’ in which the range of land holding can be as wide as between three to twenty plots per household. While inheritance is the only mechanism to transfer land ownership in this model, selling and buying land happens quite often in reality.

#### **4.4.2 Land Borrowing**

Apart from the owned and shared land, there is another mechanism to get access to land: land borrowing (for one season only). The question then is whether these arrangements can fulfil the yearly need of land for swiddens for all households.

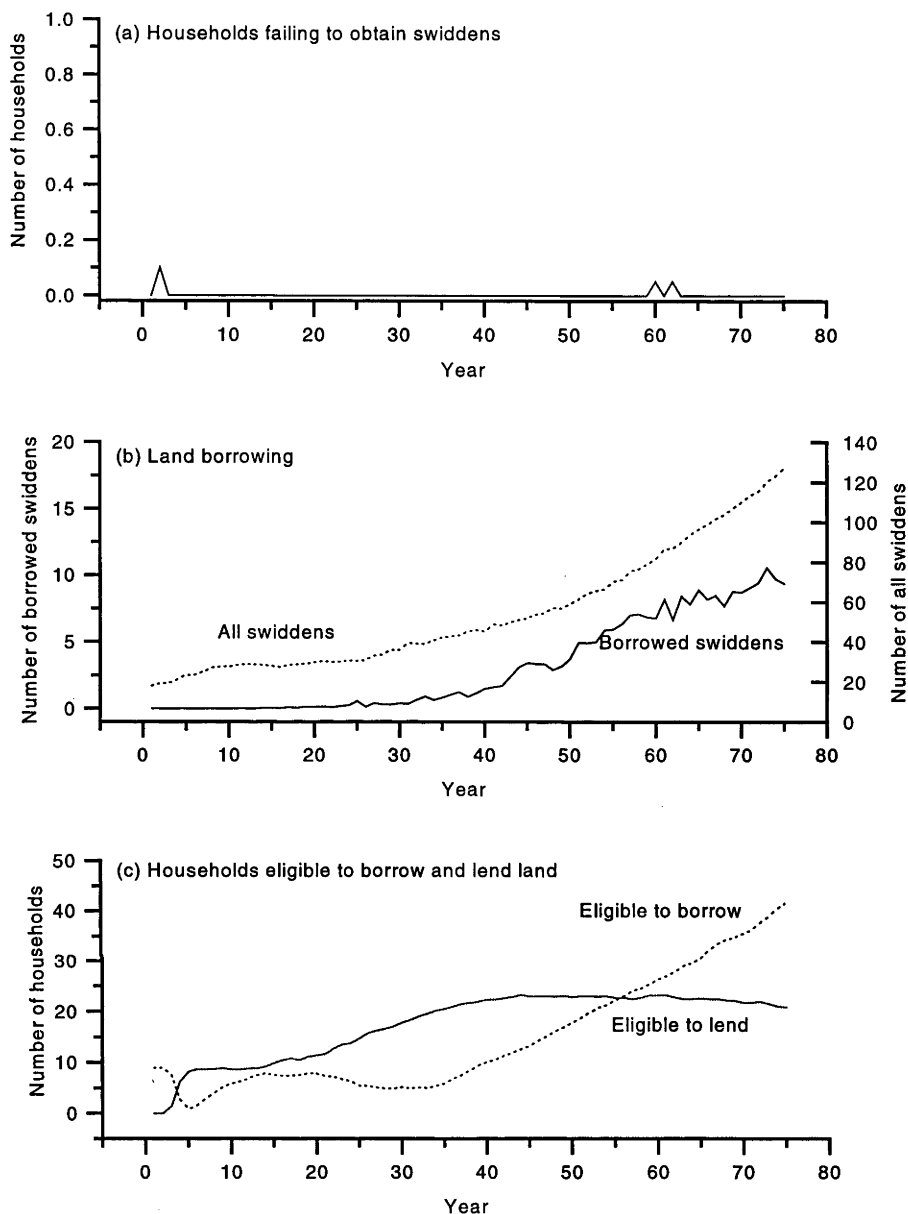


Figure 4.6 Magnitude of land borrowing.

Figure 4.6-a indicates that almost all households obtain the intended number of swiddens. Moreover, Figure 4.6-b indicates that land borrowing does play a role in facilitating some households to get temporary access to land, although the proportion to the total cultivated plots is small. To explain why frequency of land borrowing is small, recall that firstly the model imposes a constraint on who is eligible to borrow and lend land (see 3.3.4.1). Secondly, land ownership is only one among the factors

considered in swidden selection (see Table 3.4). In this regard, higher preference is given to owned and shared plots rather than to other households' plots. Thus, other households' land will be borrowed only when the site attractiveness in terms of geographical location and the vegetation type outweigh that of the owned and shared plots. Therefore, the magnitude of land borrowing should somewhat reflect the availability of land and the relative attractiveness of the available plots. Figure 4.6-b and-c show that despite the presence of eligible households, there is no land borrowing in the first 30 years. This indicates that the plots available for borrowing are less attractive than the owned and shared plots. After that, as more small-landholder households are formed, borrowing land becomes an alternative for some of these households. Nevertheless, given the magnitude of households eligible to borrow and to lend land, toward the end of the simulation, the low frequency of land borrowing reflects more about the limitation on the supply side rather than on the demand side.

#### **4.4.3 Fallowing practice**

The immediate implication of the differential land access is the length of fallow. Figure 4.7-a presents the average fallow length of all swiddens. The initially increasing fallow length corresponds to the period when the fallow plots accumulate as a result of continuing primary forest plot clearing. The fallow plots are rapidly built up so that some of them can be left for ten years or more, before their locations become favorable for swiddens. The average fallow length declines rapidly following the disappearance of the primary forest. By comparing the distribution of swiddens based on their fallow length (Figure 4.7-b) and the approximate land holding of the households practicing the fallow (Figure 4.7-c), it is clear that the differential land holding affects the fallowing practice. Those with ample access to land can observe the desired long fallow, but others are forced to shorten the fallow period (Figure 4.7-b). Note that more than half of the swiddens are made in short fallow plots at the end of the simulation while few households are able to practice long fallow.

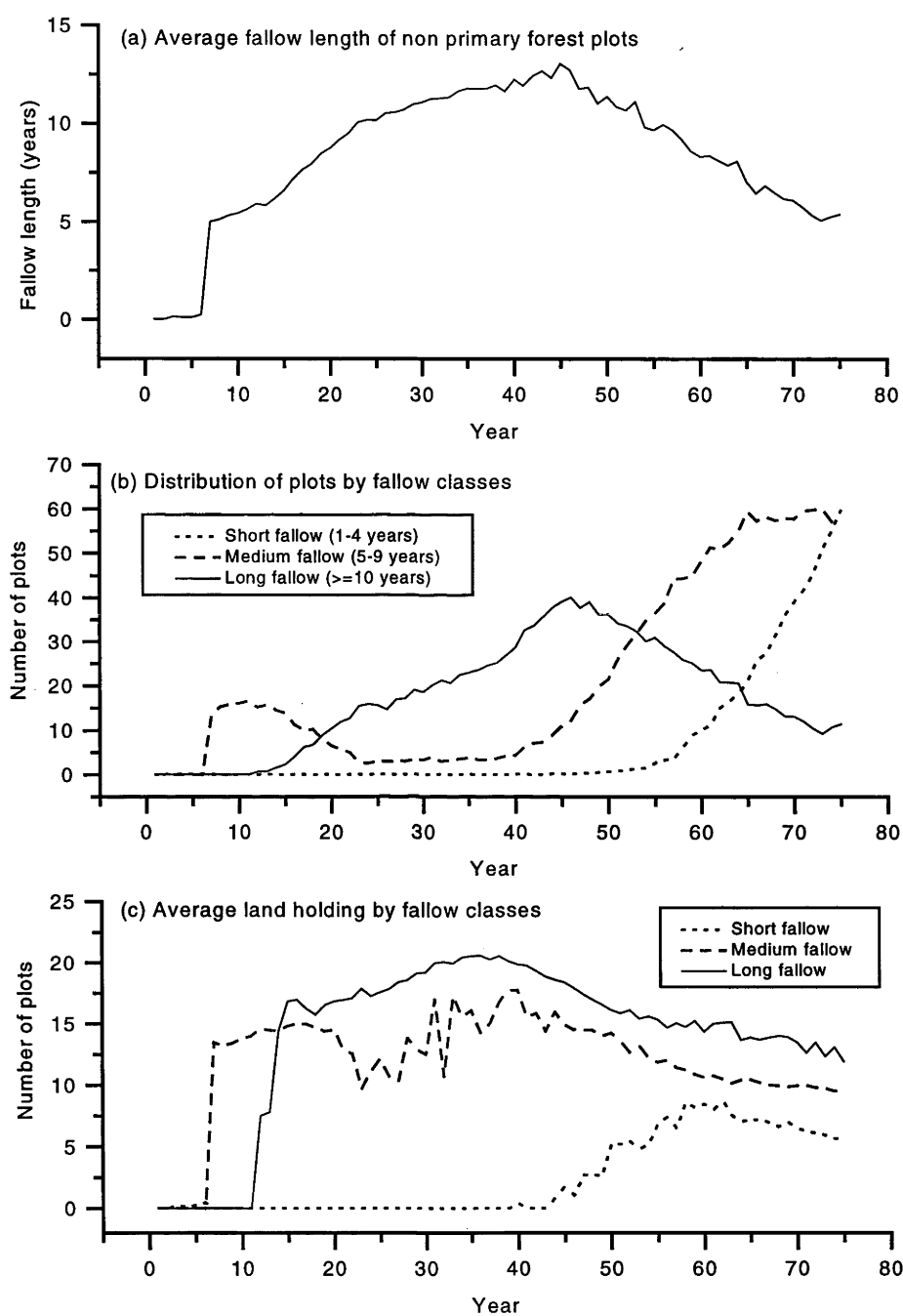


Figure 4.7 Summary of the fallowing practice. Note that, in this model, swiddens are made both in primary forest and secondary forest (fallow) plots. These particular model outputs refer only to swiddens made in fallow plots.



4.4.4 Land clearing history of the landscape

The foregoing discussion on the yearly fallow distribution tells us something about the current availability of land but it says nothing about the history of clearing, which can also be seen as the history of disturbance. The disturbance history is presented as the frequency of clearing occurring per ‘block’ of land for the entire simulation period. The pattern of clearing frequency shown in Figure 4.9-a follows a skewed normal distribution. Eighty-five per cent of land is cleared at a moderate frequency (3–11 times), 9 % a low frequency (0–2 times) and 6 % at a high frequency ( $\geq 12$  times). Finally, when it comes to the question of why some plots are cleared more frequently than the others, Figure 4.9-b suggests that, as expected, the clearing frequency correlates with the distance to the longhouse. It indicates that plots closer to the longhouse have generally been cleared more frequently than those further away.

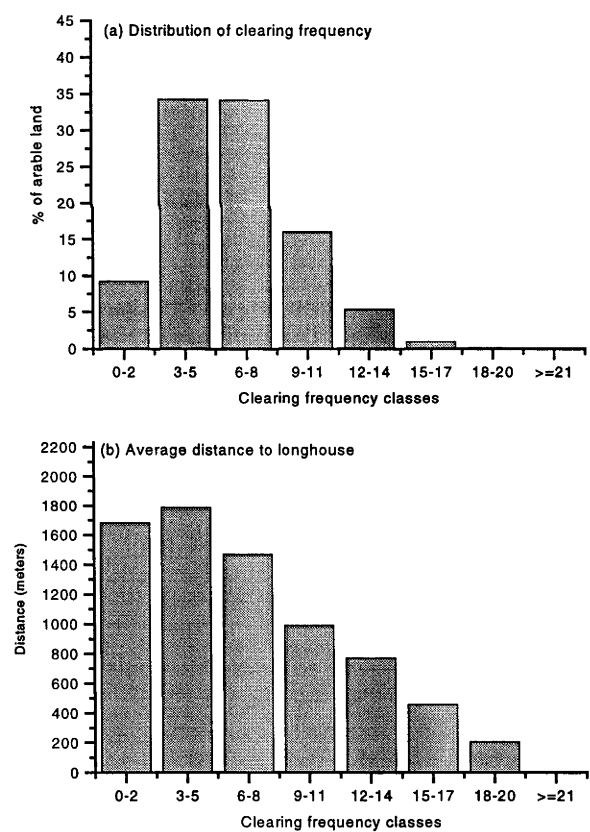


Figure 4.8 History of clearings. The land ‘blocks’ (0.5-ha unit of land) are classified according to the number of clearings during the entire simulation period.

4.5 Cultivation Schedule and the Use of Labour

While the plot selection is simulated yearly, the model simulates the carrying out of cultivation tasks on a daily basis for each individual plot. Since a stochastic process is involved in assigning the schedule, the cultivation schedule varies between plots (see section 3.3.4.2). The simulated cultivation schedule presented in Figure 4.9 depicts the range between the earliest start and the latest completion of tasks from the entire simulation period in 20-replicates, in comparison to that of the Kantu (Dove, 1985b). This figure confirms that the simulated schedule is in general agreement with the Kantu’ schedule, except the slashing of primary forest. To explain this exception, first recall that because slashing primary forest often coincides with harvesting of the last-year’s swidden the model specifies that the start of slashing has to be carried out on days with no harvesting work (see Table 3.8). The postponement of slashing primary forest until after the completion of harvest appears to be the reason explaining the wider period of the primary forest slashing in the model.

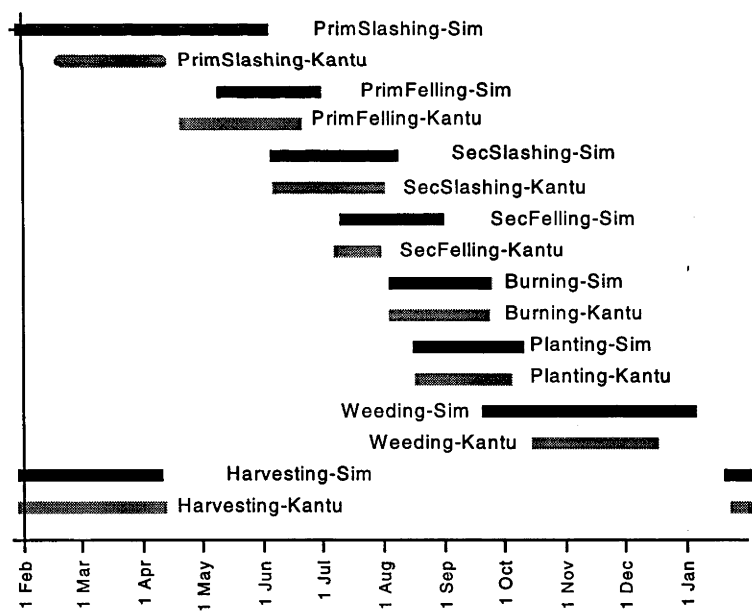


Figure 4.9 Simulated(-Sim) and the Kantu’s (-Kantu) swidden cultivation schedule

Furthermore, for each cultivation task, the model specifies the amount of labour required per hectare based on the Kantu’. Therefore, one would also expect that the

realised labour spending is close to the corresponding input data. The simulated mean of workdays per hectare for primary forest and fallow swidden<sup>3</sup> is 98 and 167 respectively, which is reasonably close to corresponding input data; 88 and 167 workdays per hectare (Dove, 1985b:377).

To illustrate the intensity of labour use at village level throughout the cultivation calendar, a snapshot of the situation at year 50 is presented in Figure 4.10. This figure reaffirms the seasonal nature of labour use in swidden cultivation with distinct busy and slack periods. The peak use of labour occurs mainly during planting weeding and harvesting. The model imposes a maximum duration within which these tasks have to be completed. When the household's labour cannot complete a task within the specified duration, external labour is hired and consequently some rice will be lost for the wage payment. In other words, hiring external labour will always signify a labour shortage. In this regard, the demand curve in Figure 4.10-c represents the number of workers that must be hired to carry out the planting, weeding and harvesting, whereas the supply curve represents the number of 'idle' workers available for hire. It suggests that the wage labour demand can be met locally during the planting and weeding season but not during the harvesting, when the un-met external labour is assumed to be filled by labour from outside of the village.

As far as labour spending at the household level is concerned, almost all households (around 90 % each year) require external labour. Figure 4.11-a shows that the average external labour requirement is between 4 – 12 % of the total labour requirement. The increasing trend could be attributed to the increasing frequency of swiddens made in fallow plots. Labour input for fallow plots are higher than for primary forest because cultivating fallow plots requires weeding (Dove, 1985b:377). The high labour input for weeding and maximum duration within which weeding has to be completed result in an increase in the proportion of external labour hired from year 5 and onward. Meanwhile, the decreasing trend toward the end of the simulation could be attributed to the general decline in the rice yield due to

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<sup>3</sup> The data are extracted from the mean labour spent in all plots at year 10 for the primary forest swiddens since during that year all swiddens are made in primary forest, whereas, those for secondary forest are extracted from year 50 for the same reason.



shortening fallow. Since the rice yield determines the labour requirement for harvesting and given the fact that harvesting is one of the tasks that require substantial external labour (Figure 4.10-c), the external labour hiring would decrease following the decline in rice yield.

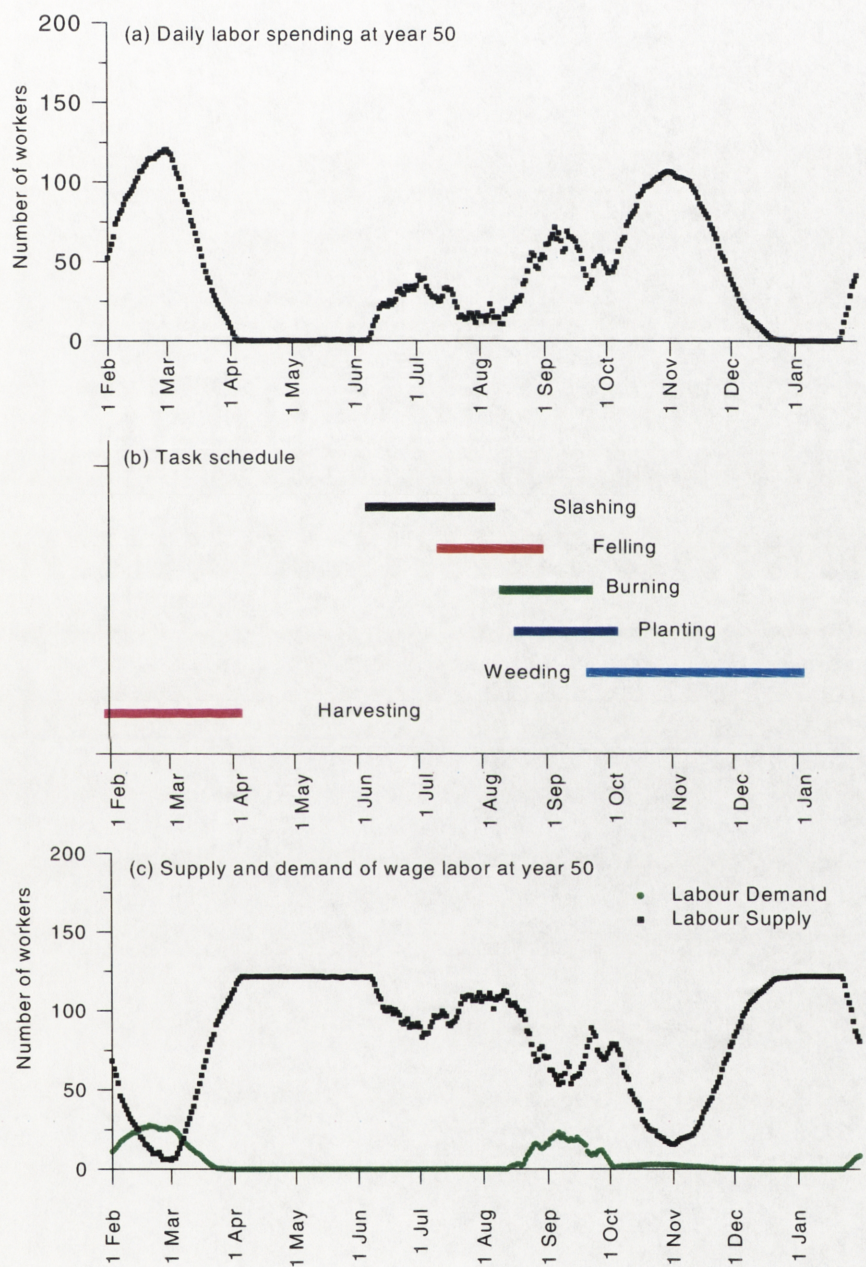


Figure 4.10 Intensity of labour use at the village level (year 50) throughout the cultivation calendar. Note that this calendar does not include tasks like making tools and carrying the harvest back to the village. In this model, the execution of these tasks is not confined to specific dates (see section 3.3.4.2).

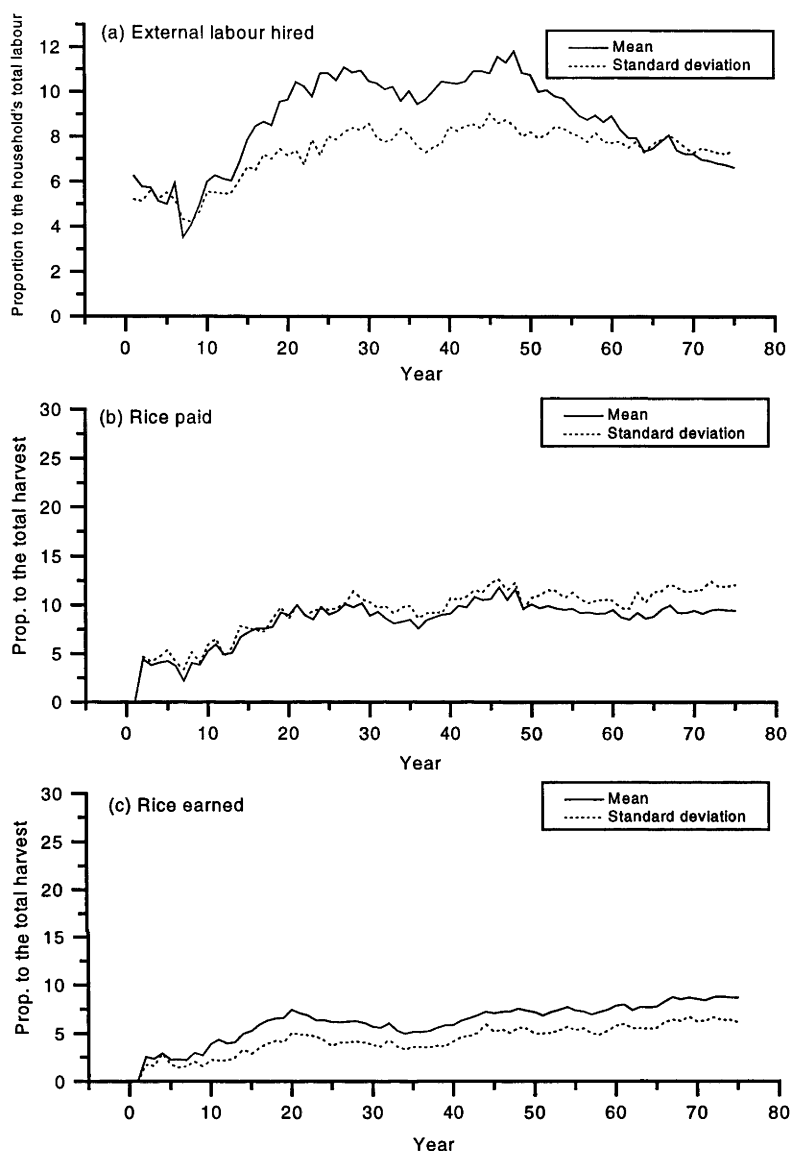


Figure 4.11 (a) Magnitude of external labour required by households to complete all cultivation tasks, (b) the associated cost, (c) the rice earned by working on other households' swiddens. In each simulation year, the mean and standard deviation of these variables are calculated. The data presented in this graph are the average of the yearly means and standard deviations for 20 simulation replicates.

The variation in the cultivation schedule among the plots, and hence the households, means that while households may lose some rice they can earn rice by working on other households' plots during the idle period<sup>4</sup>. The process of labour hiring can

<sup>4</sup> Note that, in this simulation, the chance of the short-of-labour period of one household to coincide with the idle period of the others' is stochastic.

therefore be seen as a means to maximise the use of idle labour. A comparison between the proportion of rice paid and rice earned to the total harvest reveals that the former is on average slightly larger than the latter (Figure 4.11-b and 4.11-c). The average of the means for the entire simulation is 8 % and 6 % for the proportion of rice paid and rice earned respectively. Nevertheless, the low proportion of rice paid out and rice earned is more telling than the subtle difference between the two. This suggests that the main source of rice for consumption is the rice produced from the household's owned swiddens.

The magnitude of standard deviation of the external labour hired, rice paid and rice earned is generally high; almost the same level as the means of those variables. This suggests that the variation among the households in any one year is considerable. The occurrence of households at various developmental stages with varying number of workers is obviously one source of this variation. For households with small a number of workers relative to the number of consumers, whom they have to support, the dependency on external labour is high. The total rice paid out could be as high as 50 % of the total harvest in these households.

## **4.6 Economic welfare of the community**

### **4.6.1 Rice production**

The analysis of rice production will focus not on the absolute level of production but on to what extent the overall production can meet the rice demand. But first, recall that in the model the annual rice demand, which commands the intensity of cultivation, consists of eating rice, seed rice, rice for paying wages. At the end of each simulation year, an evaluation is carried out to determine whether this annual demand can be met by the rice currently available, consisting of rice harvest, rice stored from previous-years surpluses and rice earned from wage labour. Hence, a variable called rice sufficiency is constructed, which is defined as the proportion of the rice currently available to the annual rice demand. To facilitate assessment of the differentiation among the households, households are classified into three classes as defined in Table 4.2.

Table 4.2 Rice sufficiency classes

Class	Degree of rice sufficiency
High sufficiency	Rice currently available can meet the annual demand
Medium sufficiency	Rice currently available is between 50 – 99 % of the annual demand
Low sufficiency	Rice currently available is less than 50 % of the annual demand

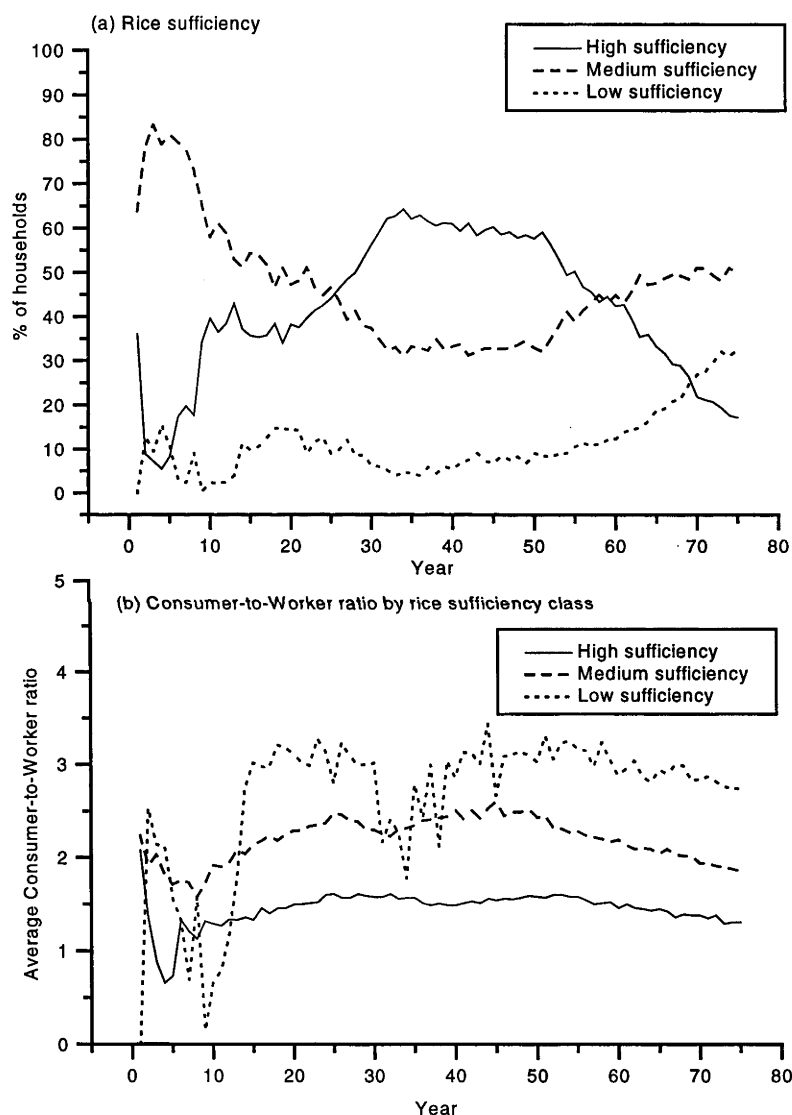


Figure 4.12 (a) Rice sufficiency level, (b) demographic constraint to rice production



The result (Figure 4.12-a) shows that, during the period of year 20 – 50, an average of 54 % of households attain the high sufficiency level, which is similar to the comparable data reported for the Kantu'. According to Dove (1985b:294), during the planting period of 1975 and 1976, 50 % of households were able to meet the consumption and seed rice requirement from the current harvest and stored rice. Nevertheless, the model result suggests a general decline in rice sufficiency level. At the end of simulation, around 80 % of the households fail to meet the rice demand. While in reality, the success of burning, pest attack and other natural factors affects the rice production, in this model the rice production is determined by access to land and labor only.

To explain the variation in the sufficiency level in relation to land and labour factors, we will examine the way in which these factors could constrain the rice production. Firstly, inequality in land holding could prevent a small number of households from obtaining the intended area of land for swiddens (see Figure 4.6-a). Although performing labour in others' swiddens could provide a source of rice income, it is generally very small compared to the demand (see Figure 4.11-c). More detailed checking of the model confirms that all households failing to obtain the intended number of swiddens belong to the low sufficiency class.

Secondly, inequality in land holding could affect the ability of households to select the most productive land. In this model, the length of fallow solely determines the level of rice yield. This means that the less productive the land that a household can access, the more land that the household needs to cultivate to fulfill the given rice demand. However, such an extension would eventually be limited by the size of labour force because the model imposes a maximum number of plots that the given number of workers can cultivate. At least two workers are required to cultivate one plot (see section 3.3.4). In such a case, the labour is in essence the ultimate constraint to rice production, although it is mediated by the lack of access to productive land.

In this regard, the study has shown that the proportion of households with small land holding increases as the population increases (Figure 4.4-a), and consequently the average fallow length decreases (Figure 4.7-a). The reduction in rice yield due to the shortening fallow is obviously a factor that explains the general decline in the rice



sufficiency level. Furthermore, this study has also established that the length of fallow correlates with the size of land holding (Figure 4.7-c) in which households with smaller land holding tend to practice shorter fallow. It is very tempting to attribute the occurrence of low and medium rice sufficiency levels entirely to the problem of shortening fallow. However, households with medium and low rice sufficiency levels appear even in the early years of the simulation during which access to land is not yet a problem. This prompts us to examine the role of the other factors of production (i.e. the labour) in detail, not in relation to the land but to the demographic structure of households.

The demographic structure of the household sets the rice demand according to the size of the household (number of consumers) and determines the size of labour force (number of workers). Thus, holding other factors constant, the larger the household, the higher the rice demand, and consequently the larger areas of swidden that need to be cultivated. With the limitation imposed on the maximum number of cultivated plots as mentioned previously, a household with two workers for example, can only cultivate one plot regardless of the number of consumers. The constraint of production in this case is not merely the number of workers but the relative ratio of consumers to workers.

The ratio of consumer to worker changes dynamically as the household goes through its developmental cycle. This ratio is likely to be high early in household formation, as the children do not yet contribute to the household's labour force, and will gradually decrease as the children reach working age. Therefore, the presence of households with a labour shortage due to unfavourable consumer-to-worker ratio could be an important factor contributing to the appearance of medium and low rice production sufficiency. An examination of the mean consumer-to-worker ratio of each sufficiency class as presented in Figure 4.12-b provides support for this contention. In interpreting this figure, I tend to exclude the irregular trend of the low sufficiency class during the early years in the analysis due to the small number involved. Nevertheless, the overall trend generally suggests that the main reason for failing to achieve the high sufficiency level in the early years is the high consumer-to-worker ratio. While households in such a state would appear throughout the simulation period, the decrease in rice yield due to shortening fallow is likely to

become the main cause for declining rice sufficiency towards the end of the simulation.

#### **4.6.2 Cash sufficiency**

The rubber production is also subsistence-oriented in the sense that the level of production is geared mainly to fulfil the cash demand for buying basic goods and paying cash debt. However, if a household cannot meet the rice demand, the rubber production will be intensified for additional cash to buy market rice to make up the rice shortfall. On the production side, several factors could constrain the rubber production including the remaining labour available after cultivating swiddens and the availability of tappable rubber plots (mature and old rubber stage). Apart from the owned rubber plots, the access to tappable rubber plots can be extended to others' rubber plots in a tap-sharing arrangement where the rubber production is equally divided between the tapper and the owner.

As in rice production, the analysis of cash production will focus on the extent to which the overall cash production can meet the cash demand. The result presented in Figure 4.13-a suggests that, during the period of year 15 – 75, an average of 37 % of households fail to meet the entire cash demand. To explain the reason for this failure, I will firstly examine whether the production is constrained by the availability of tappable rubber. In doing so, recall that the rubber tapping is calculated on worker/day/0.5-ha basis and each 0.5-ha 'block' of rubber can only be tapped for a maximum of 180 days per year (see section 3.3.5). Since the extent of tappable rubber blocks at the village level is known, I can calculate the 'potential' rubber production (kg). The extent of rubber exploitation can then be expressed in terms of the 'realised' rubber production of all households (kg) divided by the potential rubber production. Since rubber plots are essentially available for all households through the tap-sharing arrangement, the extent of rubber exploitation can be used as a proxy to indicate the availability of tappable rubber. The results presented in Figure 4.13-b show that in general the realised production is below the potential production. This suggests that the reason for the failure to fulfil the cash demand for some households is labour shortage rather than availability of tappable rubber. The

rice or cash shortfall for these households will have to be fulfilled by borrowing from other households in surplus.

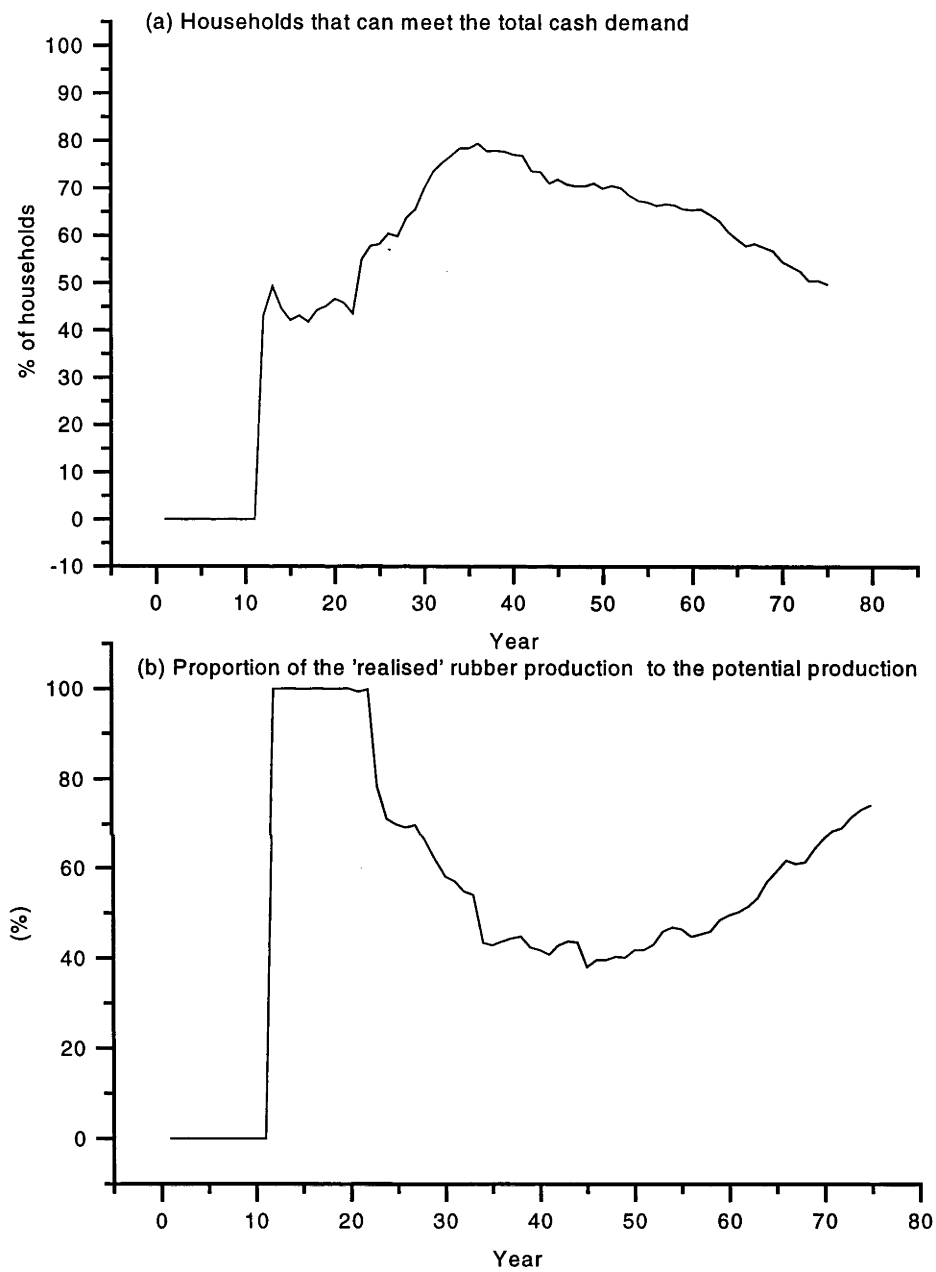


Figure 4.13 (a) Cash sufficiency level, (b) the extent of rubber exploitation in relation to the potential rubber production at village level. Note that rubber production starts after year 10; when the first planted rubber plots reach the mature stage.

### 4.6.3 Remaining labour

The final aspect of the welfare to be examined is the labour remaining after swidden cultivation, tapping rubber and working on other households' swiddens. This essentially reflects the magnitude of free labour that can be used to pursue other economic activities such as cultivating other crops or working for wages outside the village. The level of free labour is measured as the proportion of the household's 'un-used' labour (in workdays) to the household's total labour in a year. The latter is calculated as the number of workers multiplied by number of days in a year. Households are then classified into three classes: low free labor, medium free labour and high free labour, which corresponds to the level of free labour of 0 – 33, 34 – 67, more than 67 % respectively. Figure 4.14 shows that, toward the end of the simulation, most households belong to the low free labour class. The prominent occurrence of households in the low free labour class is expected given the extent of households failing to meet the cash demand presented earlier (see Figure 4.13-b). The result generally suggests that most households spend a significant proportion of labour for fulfilling basic subsistence needs. Only a small proportion of households will have the opportunity to increase welfare beyond the basic subsistence needs by pursuing other economic activities.

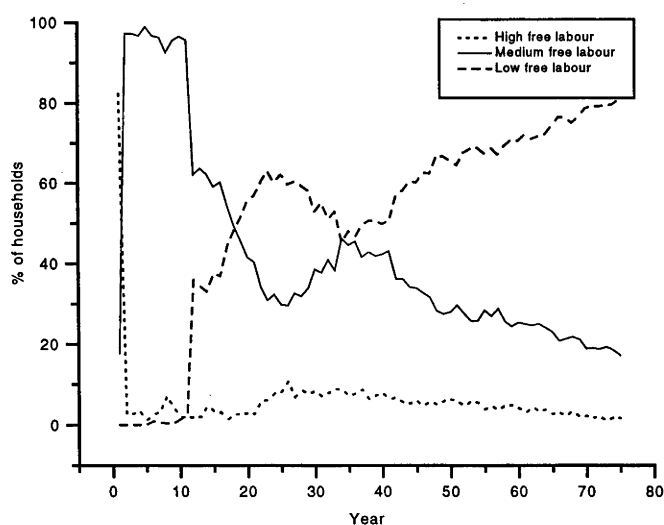


Figure 4.14 Level of free labour, measured as of the proportion of the household's 'un-used' labour (in workdays) to the household's total labour in a year. See text for the classification of free labour.

## 4.7 Conclusion

This chapter has examined the dynamics of a swidden cultivation community and its landscape under an increasing population pressure. Under 2.6 % population growth per annum, the landscape changes dramatically over the 75-year simulation period. Primary forest virtually disappears after 45 years and the landscape is progressively dominated by shrubland. From initially homogenous vegetation, the landscape is transformed to a mosaic of vegetation at different successional states. The disturbance history (frequency of clearings) also varies across the landscape. It has been shown that one reason for this variation is the farmers' preferences over the geographical location of swiddens, which results in more frequent clearings of plots that are closer to the longhouse.

This study has shown that, as the population density increases, the average length of fallow decreases, especially following the disappearance of primary forest. Such a finding is readily predictable even without the aid of a simulation. This simulation model, however, is able to demonstrate that the pressure for land is not uniformly felt across the households due to the inequality in land holding; those with ample access to land can observe long fallow practice, but others are forced to shorten the fallow period. In this model, land inequality arises as a result of stochastic demographic events that are bounded by 'social rules' pertaining to marriage, land tenure and the inheritance system. The emergence of land inequality is one of the most important findings of this study. This study demonstrates one ramification of increasing population; not simply less land available but more importantly less land are available for whom?

Apart from land, the other important aspect of swidden cultivation is the use of labour. The model successfully simulates the seasonal nature of labour use. The variation of cultivation schedules among the households means that there is a chance that the idle period of one household coincides with the labour shortage of others, which allows the temporary transfer of labour through labour hiring arrangement. The study has demonstrated that almost all households require external labour to

complete all cultivation tasks, suggesting a degree of dependency among swidden households (Wadley, 1997a).

The study has shown that most households are able to attain high levels of rice sufficiency although the number declines as the population pressure intensifies. Lack of access to productive land is one reason why a number of households fail to achieve a high level of rice sufficiency. The other reason is labour shortage induced by the demographic structure of the household; when the number of consumers is disproportionately larger than the number of workers. Furthermore, a significant proportion of households fail to produce the demanded cash. Again, labour constraints, as opposed to availability of tappable rubber, is identified as the main reason for this failure. Apart from the availability of labour and tappable rubber, the levels of rubber productivity as well as rubber price are also crucial in determining the ability of households to fulfill the demanded cash. Therefore, it is important to remember that this present result represents a situation where the level of rubber productivity is low (see section 3.3.5). Sensitivity of the cash sufficiency level to assumption of rubber price will be discussed in the next chapter. Nevertheless, under the current set of assumptions, this study suggests that most households spend a significant proportion of labour for fulfilling basic subsistence needs. Only a small proportion of households has ample remaining labour, which can be used to pursue other economic activities.

# Chapter 5

## Sensitivity Analysis

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### 5.1 Introduction

This chapter describes the use of sensitivity analysis to further evaluate the performance of the land-use model. Sensitivity analysis is a term that usually refers to a collection of methods for assessing how sensitive the model output is to changes in the parameter values (Swartzman and Kaluzny, 1987:217). In this study, the sensitivity analysis takes a different form <sup>from</sup> ~~with~~ this common approach. Here, the focus is more on changing the model's rules (or assumptions), although the changing of the model's parameters was also carried out. Therefore, this is essentially a scenario building exercise. The main objective of this exercise is to ensure that the model behaves reasonably under different scenarios and to gain more insights into the dynamics of the system. As will be shown in this chapter, experimentations with a set of either contrasting parameter values or variable rules can help to reveal the 'hidden' dynamics of the system. The simulation experiments focus on the processes that are expected to be critical in determining the land-use dynamics of the system. These include the process of site selection, the rate of land acquisition (i.e. primary forest clearing), the agricultural strategy in terms of managing food and cash crop cultivation and the effect of variation in commodity prices.

The first simulation experiment explores the implications of changing the 'weights' of the site index. The second simulation experiment deals with different rates of primary forest clearing. In the third simulation experiment, the assumption about the strong preference of growing own food (see section 3.3.4) is relaxed by allowing households to shift the priority to a cash crop (tapping rubber). In the final simulation experiment, the commodity prices are allowed to vary, and these variations are treated as an exogenous factor in the model. Through these simulation experiments, the usefulness of this model in increasing our understanding of the dynamics of a swidden agriculture system becomes more apparent.

## 5.2 Varying the weights of the site index

One of the important approaches in this model is the use of a site index to aid in simulating the process of site selection by households. The site index summarises the values of all factors that are taken into account in land-use decision. The weighting component of the site index (see Table 3.4) is particularly crucial since it reflects the relative importance of each factor on the overall decision. In this section, I investigate the sensitivity of the model to changes in the weights of the various factors used to calculate the site index. For this purpose, I designed a simulation experiment where the model is run for 200 replicates where each replicate uses a different set of weights. The weights for each replicate are created by generating eight random numbers (between 0 to 1) which are associated to a selection factor, and the sum of all the selection factors is one. The effect of varying the weights is measured by changes in the proportion of primary forest at year 40.

Figure 5.1 (a-g) plots the values of weight for each selection factor and the resulting proportion of primary forest. To extract the selection factors that are most sensitive to changing values, a forward stepwise regression analysis<sup>1</sup> was carried out in SYSTAT (1992). The analysis shows that the most sensitive factors affecting the extent of primary forest are vegetation preference, topography, and distance to longhouse, distance to river, distance from the household's other current swidden (Table 5.1). The results suggest that as the vegetation preference becomes more important (as evidenced by a higher weight), the primary forest will decline faster. In the model, each time an attempt is made by a household to clear primary forest, the chance of the attempt being realised is higher if the weights are increased. However, the nature of the relationship is reversed for the other factors. For example, as the distance to longhouse becomes more important, sites near the longhouse would be more attractive than primary forest, which would always be located further away from the longhouse. This leads to higher frequency of clearing fallow plots, which brings about slower expansion into primary forest.

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<sup>1</sup> Stepwise regression is a procedure commonly used in the multiple regression analysis for screening out independent variables that are not important in explaining the variation of the dependent variables. In a forward stepwise, the procedure incrementally adds variables into a linear equation. In each step, a variable is to be included if the value of  $t$  (or the equivalent  $F$ ), on the presence of the variables already in the equation, is the largest among the remaining variables at a specified  $\alpha$ -to-enter level (see Mendenhall and Sincich, 1988). The  $\alpha$ -to-enter level used in this calculation is 0.01.



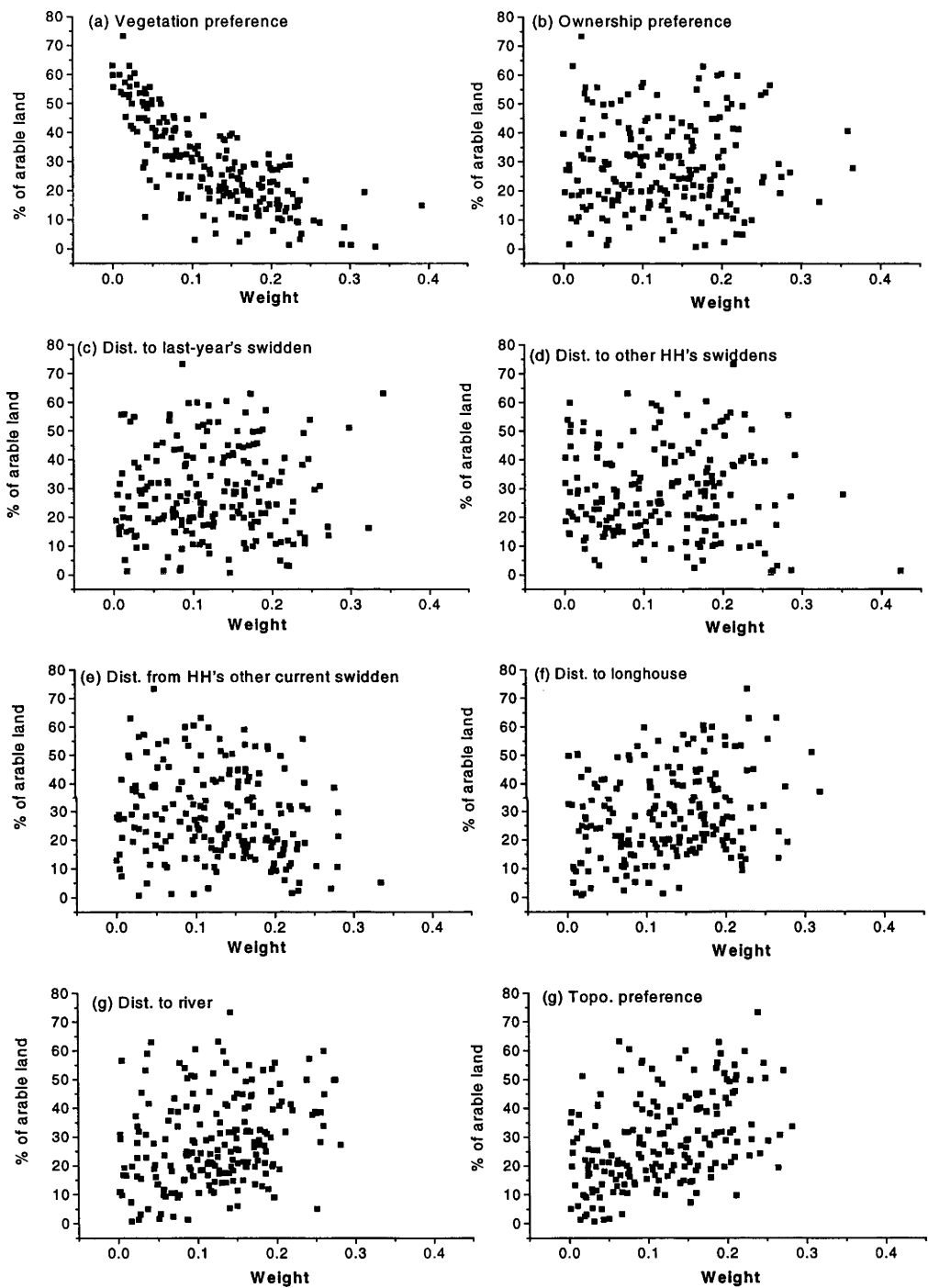


Figure 5.1 The values of weight for each selection factors and the resulting proportion of primary forest at year 40, measured as the proportion to arable land.

Table 5.1 Results of the forward stepwise regression. In the list are variables significantly explaining the variation of the proportion of primary forest at year 40.

Table of coefficients

Variable	Coeff.	Std. Err.	T	P (2 tail)	% var. explained (r <sup>2</sup> ) on entry
Constant	27.686	2.345	11.806	0.000	
Vegetation	-137.453	5.762	-23.855	0.000	60
Topography	82.375	6.064	13.585	0.000	72
Dist. to longhouse	60.336	5.988	10.076	0.000	79
Dist. to river	45.676	6.605	6.916	0.000	84
Dist. from same-year swiddens	-30.508	5.960	-5.119	0.000	84

Table of ANOVA

Source	SS	DF	MS	F-ratio	P
Regression	39707.999	5	7941.600	240.440	0.000
Residual	6407.707	194	33.029		

Changing the weights of the site index is only one among several avenues in this model whereby different rate of primary forest clearing can be expected. The simulation experiments in the rest of this chapter use the default set of weights (see Table 3.4). In the next section, the simulation experiment was designed to produce different rates of primary forest clearing by changing the assumption of the industriousness to accumulate lands.

### 5.3 Varying the rates of primary forest clearing

In this model, clearing primary forest is the main means for a household to acquire land. Under the current set of rules, the model simulates a high but realistic rate of land acquisition and thus primary forest decline (see section 4.4.1). In this section, I investigate the sensitivity of model to different rates of primary forest clearing. Primary forest decline is an important environmental issue, given its crucial role as the major source of biodiversity amongst other things. In this context, slower primary forest decline is often perceived as good. Experimentation with different rates of primary forest decline would also allow one to examine such an issue in a swidden agriculture context from both the environmental and community perspective. For this purpose, the analysis is focused on landscape dynamics and the level of rice sufficiency.

The experiment consists of three simulation modes representing communities that are essentially identical in all respects but vary in their industriousness to accumulate land. One mode represents the original (default) version of the model and the other two modes represent a more industrious community and a less industrious one respectively. The assumption used to reflect the industriousness is the frequency of attempts to clear primary forest (see Figure 3.9), as summarised in Table 5.2. Note that the assumption that households attempt to clear primary forest only when they have at least one male worker is maintained. All simulation modes start with the same initial condition as in the default mode and the results are the average of 20 replicates<sup>2</sup>.

Table 5.2 Assumptions on the industriousness of households to clear primary forest used in the three simulation modes.

Simulation modes	Assumptions
Default mode	Attempt to clear <u>one</u> primary forest plot each year. Households with at least two male workers always make an attempt to clear primary forest. Those with only one male worker have a 50 % chance to make an attempt.
More industrious mode	Attempt to clear <u>up to two</u> primary forest plots each year. The assumption for the first attempt is as in the default mode. In addition, households with at least two male workers have a 50 % chance to make a second attempt.
Less industrious mode	Attempt to clear <u>one</u> primary forest clearing each year. Households with at least two male workers have a 30 % chance to make an attempt. Those with only one male worker have a 10 % chance to make an attempt.

The dynamics of landscape composition under the three simulation modes are presented in Figure 5.2. The extent of swidden and rubber are not shown, as their trends are almost identical in all modes. Primary forest in the more industrious, default and less industrious mode is removed by about 35, 40 and 60 years respectively. These graphs firstly indicate that, over the 75-years of community development, the landscape patterns differ only in the rates of change, but the long-

<sup>2</sup> The same simulation setting (initialisation and multiple runs) also applies in the simulation experiments presented in the rest of this chapter.

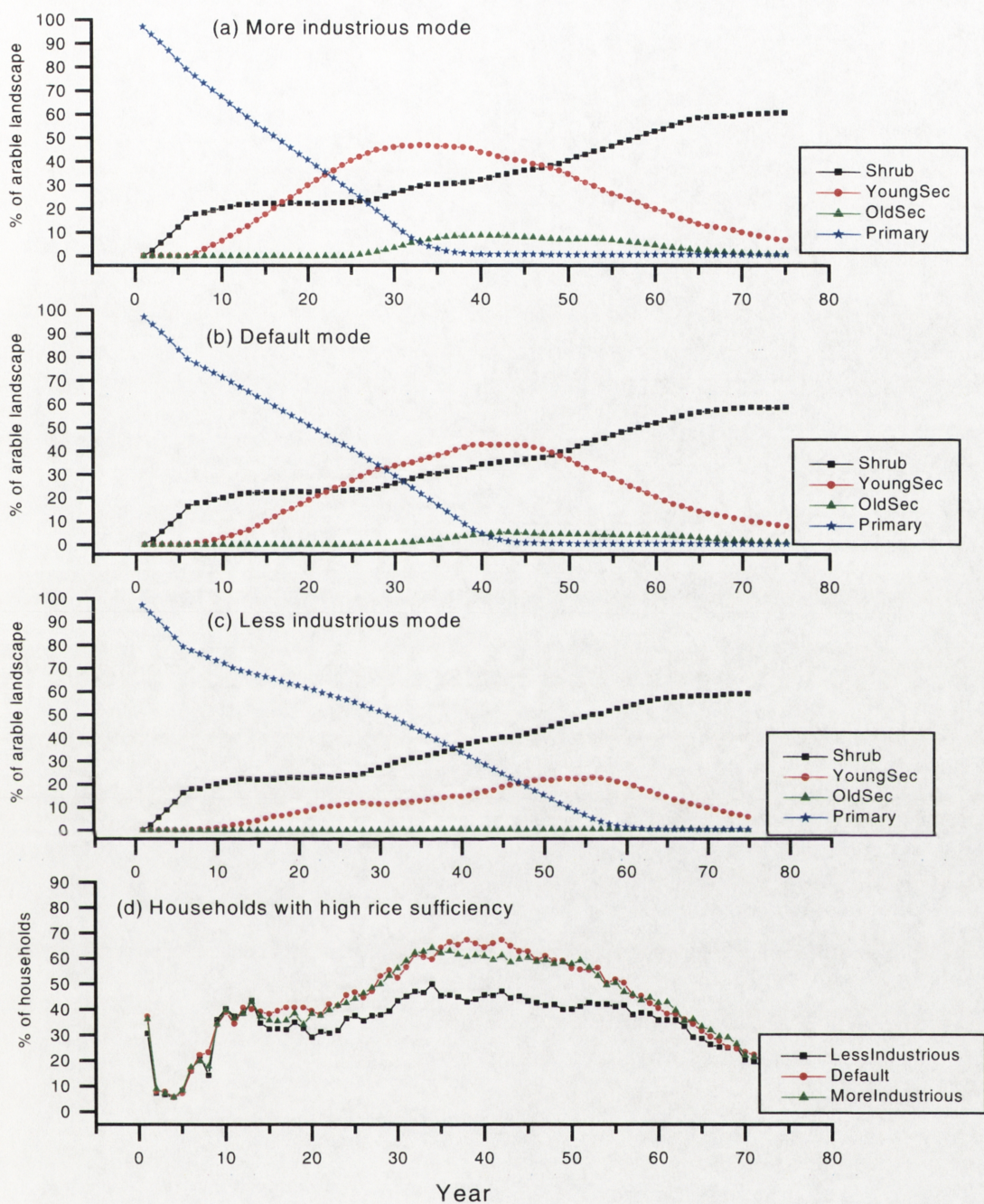


Figure 5.2 The implications of varying rates of primary forest clearing



term impacts of all the scenarios are the same, that is, the landscape is eventually dominated by shrubland. In terms of the temporal dynamics, under the highest rate of clearing (Figure 5.2-a), there are periods when young secondary forests are dominant. Note that shrubland is always dominant under the lowest rate of clearing (Figure 5.2-c).

To explain the reason for the contrasting dynamic trends first recall that in the model, each household is assumed to attempt combining making swiddens in primary forest and secondary forest (fallow plots) in a year. Secondly, note that to produce the same amount of rice for a given number of workers, the total number of cultivated swiddens would be generally the same, regardless of the type of swiddens. Thus, a higher frequency of making swiddens in primary forest must be accompanied by a lower frequency of making swiddens in secondary regrowths (fallow plots) and *vice versa*. In the more industrious mode, more swiddens are made in primary forest and so there is less conversion of fallow plots into swiddens. Consequently, a larger proportion of fallow plots is left to develop into young secondary forest and old secondary forest. In contrast, lesser clearing of primary forest in the less industrious mode means that a higher proportion of fallow plots is converted back into swiddens. Most conversions during this period occur in the young secondary forest, as this is the most preferred vegetation type and this leads to a smaller proportion of fallow plots remaining in the secondary forest stage.

As a measure of welfare of the community, I used the proportion of households that attain high rice sufficiency as defined in Table 4.2 (Figure 5.2-d). Again, the eventual outcomes are more or less the same, but there are differences in the temporal dynamics. The result shows that the level of rice sufficiency of the default mode is similar to that of the more industrious mode. The rice sufficiency levels in both modes are significantly higher than in the less industrious mode. This indicates that the level of rice sufficiency is higher under a faster rate of primary forest clearing.

To explain this trend, first note that having a large land holding would increase the chance of getting access to the most productive land, that is, long fallow plots (see Table 3.3). In the more industrious mode, the accumulation of lands occurs at a

faster rate, so, when attempts are made to make swiddens in a fallow plot, the chance to cultivate the most-productive long fallow plots is higher. Consequently, rice production and thus level of sufficiency is higher. In contrast, a slower rate of land accumulation in the less industrious mode means that only households formed earlier accumulate sufficiently large land holdings. Most households generally have small land holdings, so that, when attempts are made to make swiddens in a fallow plot, the swiddens are made mostly in the less-productive medium fallow plots. The model output on the proportion of swiddens made in long fallow plots supports this explanation; at year 40, the values of that variable are 37 %, 29 % and 11 % for the more industrious, default and less industrious mode respectively.

In summary, this simulation experiment has shown that firstly the rate of primary forest clearing can significantly affect the dynamics of secondary vegetation components of the landscape and the welfare of the community. Secondly, in this context, the changing dynamics are best understood by viewing the clearing of primary forest as a means to acquire ownership to land. Under the current set of assumptions, clearing primary forest more frequently is an advantageous strategy from the household perspective. This is because households will accumulate land faster, which enables them to secure the most productive lands.

## **5.4 Changing the agricultural strategy**

The model assumes that swidden cultivation is always given priority over tapping rubber, which reflects the agricultural strategy used by the Kantu as well as several other communities in Borneo (see section 3.3.4). This assumption implies a strong preference for growing their own food. However, one may wonder whether this is always a sound strategy in a strict economic sense. To analyse this issue, I defined a variable called the return to labour, defined as kilograms rice produced from one labour unit, to compare the ‘economic efficiency’ of producing food as opposed to focusing on tapping rubber to earn cash that is later used to buy rice. The comparison of these alternative strategies (Table 5.2) suggests that growing food is an efficient agricultural strategy for households who can make swiddens in primary forest and long fallow plots. Note that even without taking into account the benefit of acquiring land ownership, cultivating swidden in primary forest is a more efficient economic

activity than tapping rubber. However, cultivating swidden is not an efficient strategy for those that have access only to less-productive medium and short fallow plots. In this situation, the labour could be better spent by producing cash to buy rice. This simple calculation led me to the idea of modifying the agricultural strategy in the model. The modified agricultural strategy will be the one where a measure of economic efficiency is taken into account in land-use decisions. In this simulation experiment, the default mode will be compared with the modified version, which is called the ‘ flexible’ mode.

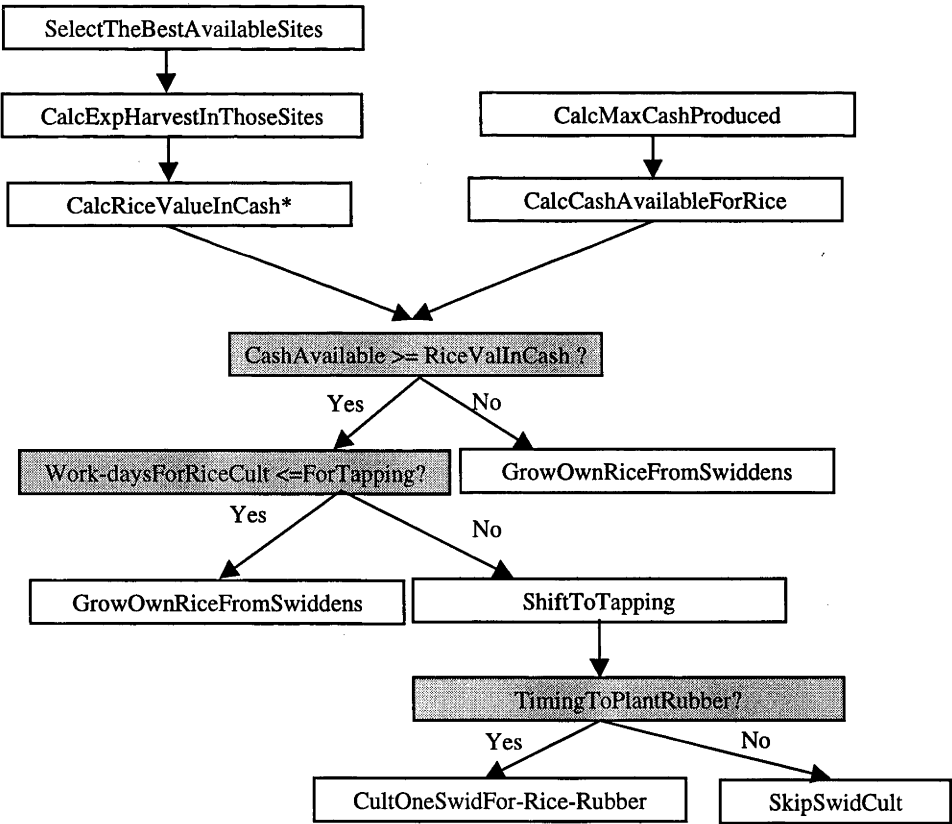
Table 5.3 Comparison of the return to labour between swidden cultivation and rubber tapping

Cultivated lands	Yield (kg)	Input labour (work-days)	Swidden, return to labour (kg/ work-days)	Tapping, return to labour (kg /work-days) <sup>1</sup>
1 ha. of prim. forest plots	500	88	5.6	3.9
1 ha. of long fallow plots	750	168	4.5	3.9
1 ha. of med. fallow plots	500	168	2.9	3.9
1 ha. of short fallow plots	300	168	1.8	3.9

<sup>1</sup>Price for un-milled rice and rubber is Rp. 83/kg and Rp. 160/kg respectively. One worker produces 2 kg rubber/day/0.5 ha. Thus, one workdays of tapping rubber is equivalent to (2x160)/83 or 3.9 kg of rice.

The flexible mode differs from the default mode only in the following aspects. It assumes that households attempt to pursue the most efficient way to obtain the rice; whether growing rice in swiddens or tapping rubber and then using the proceeds to buy rice. These two options are evaluated by considering the state of households, particularly the labour force, size of fallow and rubber holding, using a set of rules summarised in Figure 5.3. Each household first searches the best potential swidden plots available for that particular year using the same procedure as in the default mode (see Figure 3.8), except that the cultivation is not yet executed at this stage. Note that the chosen plots inherently carry information not only on the location preference but also the level of rice demand, size of fallow land holding and number of workers (see section 3.3.4.1). Since the vegetation type or fallow length of potential plots is known, the expected rice yield can be calculated. One reason for a strong preference for growing own food among swidden farmers is the benefit of producing inter-cropped vegetables and other non-rice cultigens at low opportunity cost (Cramb, 1989b:108). To account for this benefit, the model assumes that the value of non-rice cultigens is equivalent to 25 % of the rice yield. This amount plus

the expected rice yield constitute the total expected rice from swidden cultivation. Furthermore, the maximum cash that can be produced from a given extent of owned mature rubber plots and a given number of workers is calculated. The maximum cash less the amount required to buy basic goods constitutes the cash potentially available for buying rice. The household selects to tap rubber if the potential cash produced is equal or greater than the equivalent value of the total expected rice and if the labour for tapping to earn the equivalent value of the total expected rice is equal or smaller than for cultivating swidden. Otherwise, cultivating rice in swiddens is selected. This mode maintains the default mode's rule on the timing of rubber planting (see Figure 3.8) in order to achieve a similar rubber holding with the default mode. Consequently, a decision to forego swidden cultivation is overridden when the rubber planting is due; in this case, one swidden for-rice-and-rubber is cultivated.



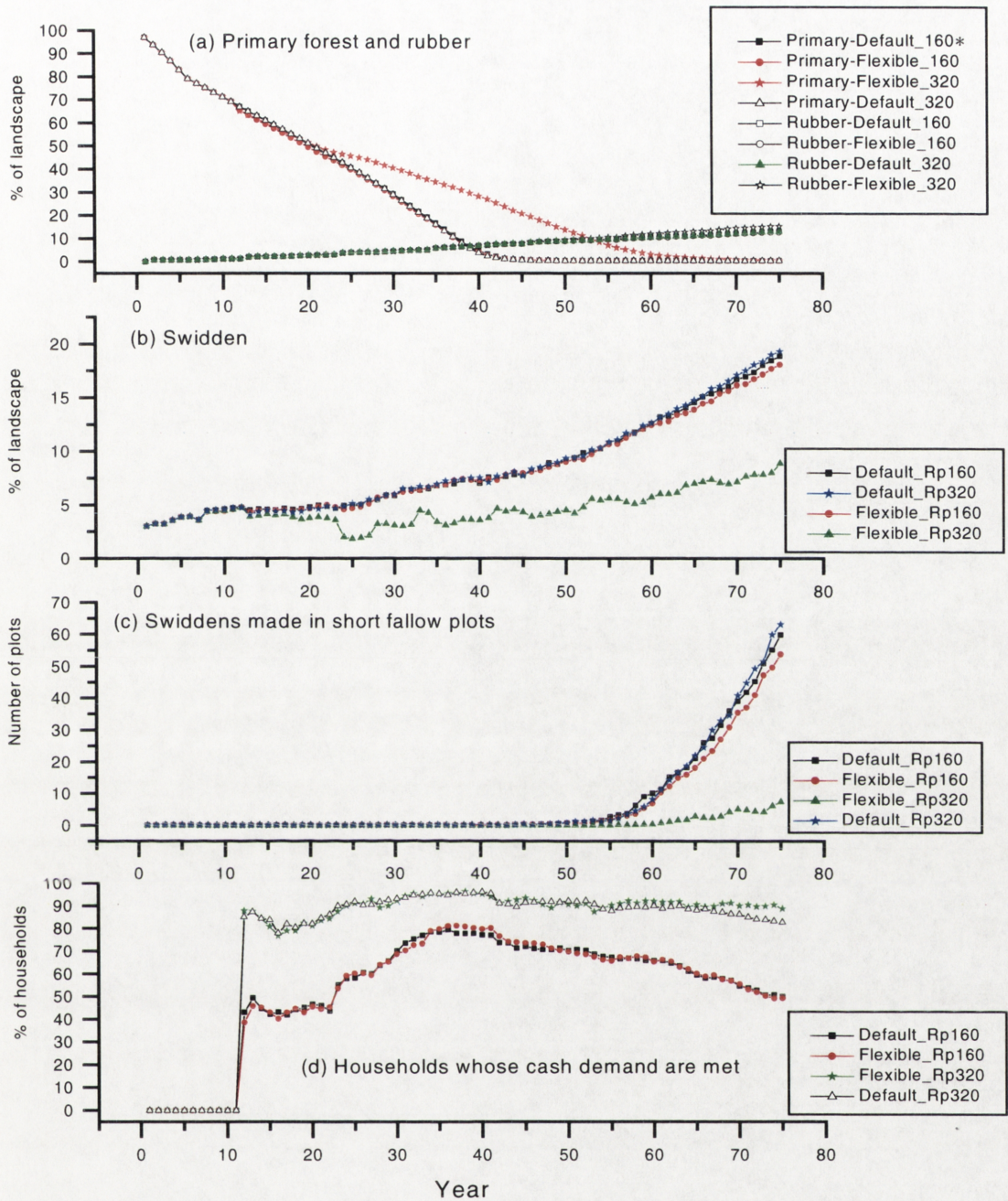
\* Including account for the value of non-rice cultigens

Figure 5.3 Set of rules in the flexible mode to determine the intensity of swidden cultivation and rubber tapping.



In this experiment, the sensitivity of the model to the assumption of rubber price is also examined. For this purpose, the two contrasting agricultural strategies were run under two different assumptions of rubber price, which represent the default price (Rp 160) and the doubled price (Rp 320). Thus, the experiment consists of four simulation modes: default\_Rp160, default\_Rp320, flexible\_Rp160, and flexible\_Rp320. The comparisons will focus on selected variables: the magnitude of primary forest, rubber plots and swidden, frequency of swiddens made in short fallow plots and the level of cash sufficiency, which are presented in Figure 5.4.

The simulation results indicate that the extent of rubber in all modes is virtually the same (Fig. 5.4-a), as intended by the simulation design. Thus, the magnitude of the rubber holding is unlikely to be the reason for any differences between the simulation modes. The flexible agriculture strategy makes only a small difference at the Rp 160-price level, as shown by the almost identical trends of the flexible\_Rp160 and the default\_Rp160 modes. Prior to obtaining this result, I expected more noticeable differences than those shown in these graphs. In particular, I expected that toward the end of simulation, there would be a growing number of households having access only to medium and short fallow plots and those households would have shifted to tapping rubber, considering the return to labour shown in Table 5.3. The impact would have been a lesser proportion of swidden than in the default\_Rp160 mode. The simulation results show that some shifting to rubber tapping by households with limited access to land does occur, as shown by a slight decrease in the incidence of short fallow rotation (Figure 5.5-c). Nevertheless, the impact on the overall extent of swidden cultivation is subtle (Figure 5.5.-b), contrary to my expectations. The fact that my expectation is not realised indicates that there are other factors, which are not readily seen through a simple measure like return to labour, that make many simulated households consider cultivating short fallow plots as a better choice than shifting to tapping rubber at this price level. These factors include the availability of labour and the size of owned mature rubber. These results suggest that, at Rp 160-price level, cultivating swidden is generally a more efficient way to obtain rice.



\* The trends of primary forest in the default\_160, flexible\_160 and default\_320 modes are identical.

Figure 5.4 The implications of different agriculture strategies: the default mode and the flexible modes, both are run under two rubber price assumptions: Rp 160 and Rp 320.

A noticeable difference between the flexible and default strategy appears when the rubber price is doubled. The comparison between the default\_Rp320 and flexible\_320 indicates that, at this price level, shifting to tapping rubber is a more efficient strategy to obtain rice on many occasions, as shown by the significant decrease in the extent of swidden cultivation. The decrease in swidden cultivation occurs from the early years in the simulation, which indicates that tapping rubber is an even better strategy than cultivating primary forest in many cases. Consequently, the primary forest declines at a slower rate than in the default\_Rp320 mode. Moreover, this price level is sufficiently high, that it provides a strong incentive for a significant proportion of households with limited access to land to shift into tapping rubber, as shown by the sharp drop in occurrence of swiddens made in short fallow plots. However, there are still a few households who cultivate short fallow plots instead of tapping rubber. These households are likely to be those having no mature rubber plots.

Figure 5.4-d suggests that the price level significantly affects the level of cash sufficiency in both flexible and default modes. Higher rubber price leads to higher level of cash sufficiency, simply because to acquire the same amount of cash, lesser tapping is needed. The agricultural strategy has no effect on the level of cash sufficiency at the Rp 160-price. The fact that most households in the flexible mode behave like those in the default mode at this price level (see section 5.4) explains the similarity of the level of cash sufficiency. The agricultural strategy has almost no effect at the Rp 320-price. In summary, the overall trends indicate that the level of cash sufficiency is insensitive to the type of agricultural strategy but sensitive to the rubber price level.

The experiment with the flexible modes yields interesting insights into the interconnections between commodity prices, access to land, and labour. As expected, a higher rubber price leads to improving welfare of the community in general. In reality, however, the price of an export commodity like rubber fluctuates (e.g. Barlow *et al.*, 1994:10; Cramb and Reece, 1988:118). In the next section, the assumption of constant price is relaxed by incorporating a fluctuating price for rubber.



## 5.5 Incorporating fluctuations in commodity prices

The literature suggests that the level of agriculture production from smallholder rubber/swidden farmers is not immune to rubber prices. Several reports suggest two contrasting farmers' responses to rubber price fluctuation. First, Boeke (1953:40) reported that Indonesia's smallholder rubber farmers follow an inverse supply curve in a sense that "... when rubber prices fall the owner of a grove may decide to tap more intensively, where high prices may mean that he leaves a larger or smaller portion of his tappable trees untapped". Geddes ( cited in Dove, 1993:143; 1954) suggested that farmers responded in this way because the money is generally sought for a specific need. Thus, the intensity of tapping tends to be governed by the nature of the cash demand rather than the value of rubber itself. In contrast, Cramb (1993) found that the Iban farmers in Sarawak responded to rubber price fluctuations by varying the intensity of cultivation between rice and rubber. When the price of rubber was high, the farmers concentrated more on tapping rubber, and decreased the size of the swidden. Apart from tapping more rubber, an increase in rubber planting was also reported in Sawarak particularly following the rubber price boom caused by the Korean War in early 1950s (Cramb and Reece, 1988:118-120). As for the Kantu', Dove's (1985b:33) emphasis on the importance of the subsistence aspect on the Kantu economy seems to suggest that a major shift into rubber cultivation at the expense of swidden cultivation would less likely be the case.

This section presents a simulation experiment that compares two different agricultural strategies in responding to rubber price fluctuations. The experiment uses two simulation modes presented in the previous section, i.e. default and flexible mode, but they are run under a fluctuating rubber price scenario. Dynamics of the flexible mode would to some extent be in parallel to the above-noted situation described by Cramb (1993), although in this model, instead of reducing swidden size, the cultivation itself is abandoned. Planting more rubber in response to rubber price increase, however, is not simulated. Meanwhile, the intensity of rubber tapping in the default mode would represent the situation described by Boeke (1953:40). Theoretically, shifting the emphasis on cash cropping, which is not as extensive as swidden cultivation, when the crop price is favourable will leave more land for fallow and this could temporarily ease the pressure on land. Comparing the dynamics

of the default and flexible modes in this experiment also enables one to assess the extent to which temporary shifts to cash crop eases the pressure on land. In this section, the default and flexible modes, which are run under a fluctuating rubber price scenario, are called `default_fluc` and `flexible_fluc`, respectively.

Rubber production in this exercise is seen particularly in terms of its economic efficiency compared to swidden cultivation as a means to provide rice for consumption. Therefore, apart from rubber, the price of market rice is also crucial. The Indonesian statistics show that the prices of both commodities are variable (Figure 5.5-a and 5.5-b). However, in this context, the relative prices between the two are probably more relevant than the absolute prices. To simplify the scenario of price changes in the model, rice price is held constant but the rubber price is changed according to a function that specifies the ratio between the rubber and rice prices. Figure 5.5-c shows that the Indonesian rubber-rice price ratio fluctuated over the 1968-1995 period and the price of rubber was always higher than for rice. In this simulation experiment, I prescribed a function that determines the relative price of rubber compared to rice (Fig. 5.5-d) and used it as input. The rubber price as presented in Table 3.9 is used as the base price. Note that the fluctuating price is introduced only after year 15, after which, most households would have productive rubber plots. The simulated price fluctuates in approximately 10-year cycles with the highest and lowest ratios of 2.5 and 0.5 respectively.

The results show that, as expected, the extent of swidden cultivation fluctuates inversely corresponding to the rubber price in the flexible mode, but it never ceases completely (Figure 5.6-b). The periods of low rubber prices before about year 40 triggers the clearing of primary forest in the flexible mode and this eventually brings about the same rate of primary forest decline as with the default mode (Figure 5.6-a). An occasional shift into tapping rubber, thus foregoing swidden cultivation, significantly alters the fallow regime in which households are generally able to observe longer plot rotations (Figure 5.6-c). The trends on the average fallow length suggest that the flexible strategy permits a more environmentally-sound practice in general. However, for households with a limited access to land, its effect in avoiding

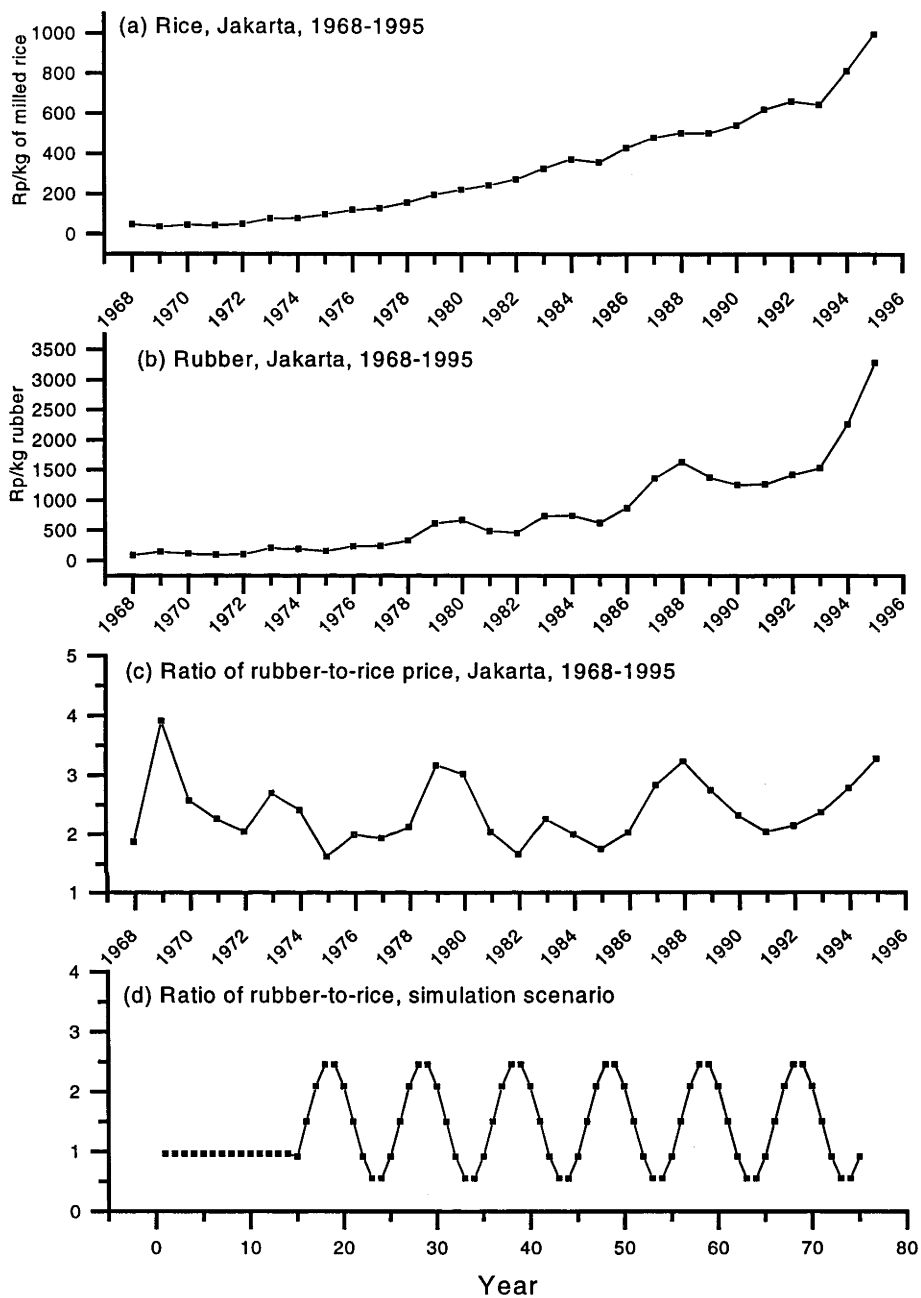


Figure 5.5 (a-c) Statistics of rice and rubber price in Jakarta market, Indonesia, 1968-1995, compiled from Statistical Yearbook of Indonesia (Central Bureau of Statistics, 1975, 1976, 1981, 1985, 1990, 1995), (d) rubber-to-rice ratio used to simulate rubber price fluctuation.



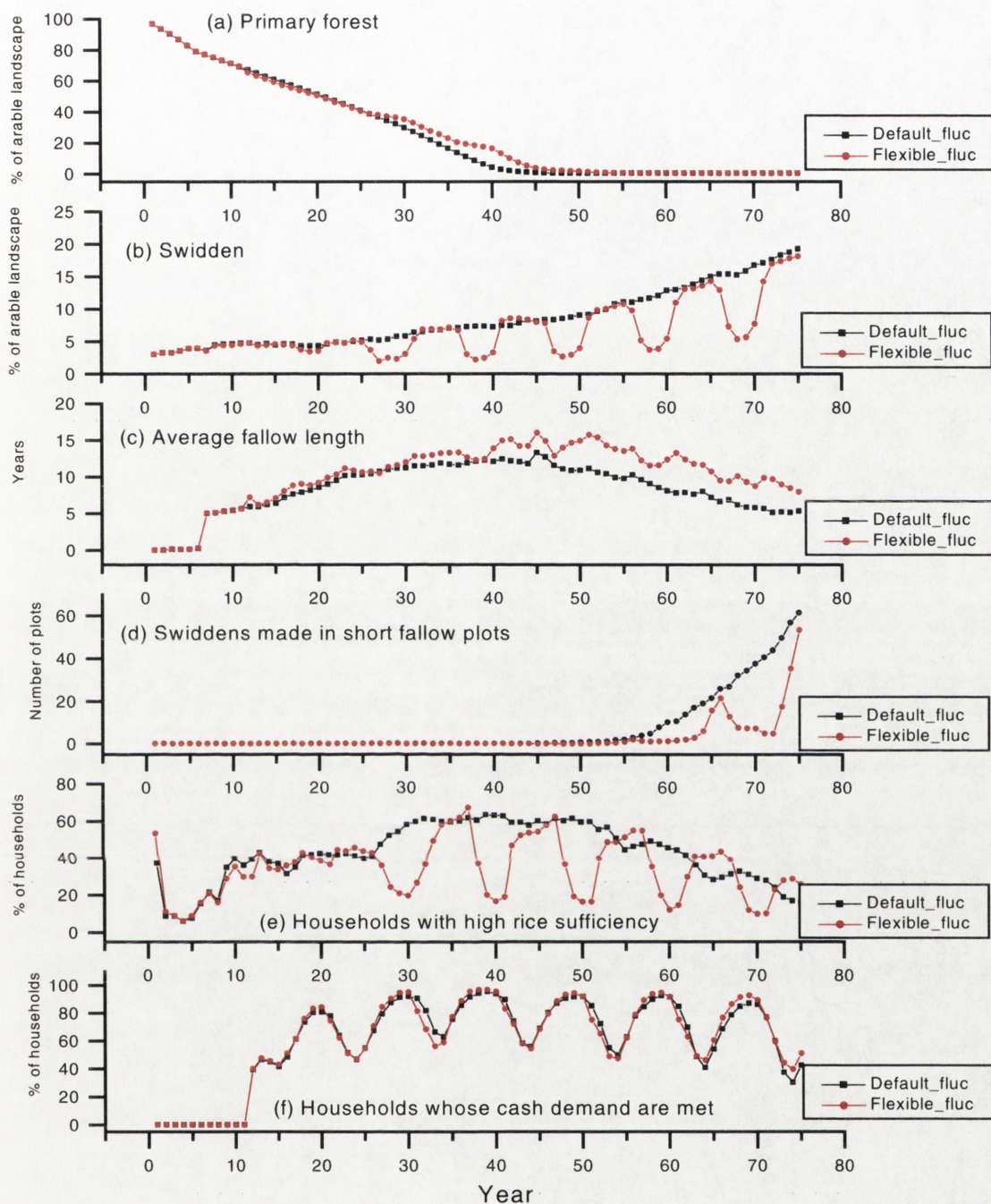


Figure 5.6 The implications of rubber price fluctuation under the default mode and the flexible mode.

environmentally-bad practice, i.e. making swidden in short fallow plots, is only temporary (Figure 5.6-d). For these households, short fallowing can be avoided during high-price years but not after several successive low-price years. The timing and duration of low-price years seems to be the critical factors in this respect. A prolonged low-price period will eventually trigger the short fallowing practice. These results raise an important issue with regard to the specific nature of price fluctuation and its impact on the dynamics of the system. Further simulation experiments with varying scenarios of price fluctuation would certainly be an interesting exercise to pursue in the future.

The impact of different agricultural strategies on the level of rice sufficiency is shown in Figure 5.6-e. It shows the proportion of households with high rice sufficiency as defined in Table 4.2. Note that the amount of rice accounted for in this measure refers to the rice produced in swiddens, thus excluding rice bought from the proceeds of rubber. Thus, the occasional drops observed in the flexible mode is a consequence of foregoing swidden cultivations during years with a low rubber price. However, the most important point shown in this figure is that there are more households achieving high rice sufficiency during the years with low rubber prices in the flexible mode than in the default mode during the last-25 years, when the land pressure is high. Temporary shifts into tapping rubber during the good-price years leaves lands in fallow for a longer period. As the land productivity increases under a longer fallow period, this action would give households a better quality of land at the time when they have to cultivate swiddens during the bad-price years.

In terms of cash sufficiency, the default and flexible mode exhibit largely the same pattern, which corresponds to the price fluctuation. When the rubber price is at its height, almost all households can meet the cash demand and, when the price is at its lowest, only around 40 % of households can do so. The similarity of the trends between these two modes is to be expected, given the insensitive nature of this variable to the type of agricultural strategy presented on the previous section. It is interesting to note that even when the rubber price is high, not all households are able to fulfil the entire cash demand. Severe labour constraint seems to be the main reason for this failure.



The results from the experiment with the flexible agricultural strategy provide a valuable lesson in exploring the alternative paths of the swidden agriculture system under increasing population pressure. For example, in an area with limited capacity for territorial expansion, increasing population could lead to decreasing length of fallow, which eventually brings about decreasing swidden production. Greater involvement in cash cropping or other cash earning activities seems unavoidable to ensure the survival of households in such a situation. However, involvement in cash cropping always entails a risk of a low return when the commodity price drops. From this exercise, one can infer that, rather than permanently replacing swidden cultivation with cash cropping, maintaining swidden cultivation as ‘an option’ in the farming system could be a safer strategy to moderate the impact of commodity price fluctuations. Swidden cultivation could be used as a buffering activity to ensure some level of subsistence when the price of a cash crop is low (Cramb, 1993).

## 5.6 Conclusion

This chapter has demonstrated that model experimentation with contrasting parameter values and different rules is a useful exercise to gain more understanding about the dynamics of the system. The experiment on varying the weights of the site index has shown that the most sensitive site selection factors affecting rate of primary forest clearing are vegetation preference, topography, and distance to longhouse, distance to river and distance to <sup>and</sup> <sub>l</sub> from the household’s same-year swidden(s). The next experiment further shows that the rate of primary forest clearing can significantly affect the dynamics of the secondary vegetation component of the landscape as well as the fallow regime, which in turns affects the rice productivity. This suggests that the numerical values of the weight’s used to compute the site index will have important effects on the dynamics of the system. The fact that the model simulates a realistic rate of primary forest clearing (see section 4.3) can be taken as an indication that the current set of weight values (see Table 3.4) represents a reasonable approximation on how farmers weigh the relative importance of factors considered in selecting swidden sites.

The experiment concerned with varying the rate of primary forest clearing also revealed a contrary viewpoint. In particular, a slower rate of primary forest clearing

is often perceived as a good thing, but the experiment showed that this is not always the case in the swidden agricultural context. Here, clearing primary forest is the main means to accumulate lands. From the household perspective, accumulating land faster is an advantageous strategy because it enables households to observe long fallow rotation, which is the most productive form of swidden cultivation in this model. Furthermore, the experiment with a flexible agricultural strategy yields important insights on the alternative paths of a swidden agriculture system under increasing land pressure. The experiment has shown that shifting the priority of labour and land resource use between swidden cultivation and rubber tapping according to their economic efficiency at the prevailing commodity prices could result in a 'better' form of farming system.

# Chapter 6

## Discussions and Conclusions

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### 6.1 Introduction

This study was designed with the primary objective of developing a modelling framework that integrates the demographic, socio-cultural, economic and ecological factors affecting landscape dynamics so that (1) the agents of land-use decisions, i.e. individuals and households are explicitly represented, and (2) land-cover changes are spatially simulated. In this final chapter, the contribution of the model in understanding the swidden system of the Kantu' is presented in three parts. The first part discusses the issues of model validation. This is followed by a summary of the major findings of this study. The third part discusses the main strengths and weaknesses of the current model and this is followed by suggestions for future work.

### 6.2 The question of model validation

Validation is a thorny issue in the field of ecological modelling, and this is reflected by the different interpretation among ecologists on its meaning and importance (see Rykiel, 1996 for a review). Validation is usually taken to mean the process of demonstrating whether the model simulates observed behaviour to some pre-specified level of accuracy consistent with the intended application and within its application domain (Brown and Kulasiri, 1996). Operationally, it is commonly carried out by comparing the model outputs with data that are independent of those used to construct the model (e.g. Botkin, 1993; Shugart, 1984).

One obvious question is whether every model should be validated. Rykiel (1996) suggested that depending on the purpose of the model, one may argue that validation is not a useful activity, and this view is also shared by Mankin *et al.* (1977). In some situations, validation might be difficult or impossible simply because of the lack of data. When the purpose of the model is to make quantitative predictions, validation tests may be deemed necessary. However, when the purpose of the model is to gain insight about how a system operates, or to systemise knowledge and/or develop

theory, formal validation is not always necessary (Caswell, 1988; Rykiel, 1996). Rykiel (1996) argued that “model development is a significant scientific contribution in itself without any validation tests being undertaken in addition”.

Given my study’s objective of focusing on exploring the feasibility of the individual-based approach for land-use modelling, and the usefulness of this approach in advancing our understanding about swidden agriculture systems, then validation tests in a strict sense are less important in this study. The current version of the model also deliberately omits several phenomena that appear to have become important in recent years, e.g. swamp-rice cultivation, temporary out-migration and a renewed interest in growing pepper. Thus, a degree of discrepancy between the model output with reality is expected.

If one wished to conduct a ‘formal’ model validation on this type of model, a validation procedure similar to that used by An *et al.* (2001) could be conducted. Their model was a household-based, stochastic model that simulated the impact of various household demographic and socio-economic interactions on the amount of fuelwood use. The authors of this model conducted interviewed 45 households. Data from 30 households was used to construct the model, while the data from remaining 15 households were used for model validation.

In this study, rather than conducting a ‘formal’ model validation, a broad assessment of model performance has been presented throughout this thesis in the form of comparisons of the outputs with available data. The focus of those comparisons was not so much on the exact magnitude of data agreement but more on the range and plausibility of the model output’s trends. The summary of several key comparisons is presented in Table 6.1. The simulated population growth is close to that of the study area (section 2.4.1). The simulated pattern of distribution of household size is similar to that of the Borneo communities (section 2.4.3). For the land-use variables, the rate of primary forest clearing is very close to that observed in the study area (section 4.3). However, the rate of land holding accumulation for the nine initial households is slightly slower than that observed among the pioneering Kantu’ households (section 4.4.1). The model simulates the emergence of land inequality as the community develops. Although I was not able to conduct a quantitative comparison,

a degree of land inequality was observed during my field trip and it has also been reported in many swidden agriculture communities (section 4.4.1). These comparisons suggest that, in general, the model behaves realistically with respect to gross population and landscape characteristics.

Table 6.1 Comparisons between model outputs and empirical data.

Variables	Model output	Observations	Data source
Population growth	2.6 % <sup>1</sup>	2.1 – 3.9 %	Population of Nanga Kantuk village 1984-1999 (field note, 1999)
Distribution of household size	Similar <sup>2</sup>	Similar	Selected Borneo Communities <sup>3</sup>
Disappearance of primary forest	Around year 45	Gone by 1999 or 42 years since init. settl.	The Kantu' (field notes, 1999)
Number of cultivated swiddens per household	1.4 – 2.6 over the entire period	2.3	The Kantu' (Dove, 1981)
Land holding of the initial households at year 20	31 ha	26 ha	The Kantu' (Dove, 1985b)
Land inequality	Present	Observed <sup>4</sup>	The Kantu' (field note, 1999)

<sup>1</sup> Average rate for 75 years

<sup>2</sup> Statistically identical according to the Kolmogorov-Smirnov test at  $\alpha = 0.01$  (Sokal and Rohlf, 1981).

<sup>3</sup> Summarised data (Dove, 1981; Drake, 1982; Freeman, 1992; Wadley, 1997a, Dove, pers.comm).

<sup>4</sup> But the exact magnitude is unknown

### 6.3 Summary of major findings

The major findings about the dynamics of the swidden cultivation of the Kantu' derived from the simulation experiments (Chapters 4-5) are summarised in Box 6.1.

### Box 6.1 Summary of the major findings

- The simulated population grows at about 2.6 % per annum. As the population increases, the primary forest declines and is usually lost by year 45. The landscape tends to be progressively dominated by shrubland, but the rates at which this occurs vary depending on the precise assumptions and parameterisations of the model. These variations are all consistent with observations and common sense expectations.
- The households' concern over minimising travel time largely sets the pattern of agricultural expansion into primary forest, which starts from the areas around the longhouse and along the river and extends outward. Meanwhile, the households' concern over working in a group leads to the formation of clusters of swiddens.
- There are two critical periods in the development of a community that determines the distribution of land holding amongst the households. The first is before the disappearance of primary forest where clearing primary forest is the main means to acquire land. The second is after all primary forest has been cleared and land inheritance is the only mechanism to acquire land.
- Households with a higher chance to achieve large land holding are those with the following demographic advantages: (1) being formed early, (2) having many sons and (3) experience fewer out-marriages.
- As the community develops, land inequality emerges resulting in differential access to productive land, which in turn determines the ability of a household to satisfy its demand for rice. However, access to productive land is not the only determinant as another important determinant is the size of household's labour force in relation to the number of consumers.
- There is a significant degree of dependency among households because most households require external labour to complete all their swidden cultivation tasks. The external labour is particularly needed to complete the time-constrained tasks of planting and harvesting.
- In a situation where tapping rubber can substitute swidden cultivation as the means to acquire rice, the rubber price is critical in determining which one is a more efficient method for acquiring rice. Generally, growing rice in swidden is more efficient when rubber price is low.
- In general, population pressure in a swidden agriculture system leads to decreasing fallow period, declining rice production and thus increasing the role of cash income from rubber for fulfilling the households' overall consumption needs. The decreasing fallow is a major concern, since it could lead to deterioration of the environment.  
~~(should the words be 'decline in productivity')~~
- Even without any technological improvement, the potential negative impacts of swidden cultivation can be lessened simply by modifying the agricultural strategy by focusing on tapping rubber during periods with high rubber prices.

## **6.4 Main strengths of the model**

### **6.4.1 Extensive treatment of socio-cultural factors**

This study has demonstrated that the individual-based approach used to represent the human component of the system facilitates inclusion of socio-cultural factors, particularly the local institutional control on the use of land and labour resources. Despite often being identified as potentially important factors in affecting land-use (e.g. Campbell *et al.*, 2000:350; Mertens and Lambin, 2000:491), socio-cultural factors are rarely included explicitly in existing land-use models. Therefore, the inclusion of socio-cultural factors in the model is an important contribution from this study. The most distinct features of the socio-cultural phenomena in this model are the organisation of individuals into households, and the consequent interactions between land inheritance and the land tenure system.

The explicit representation of persons within households allows the magnitude and gender composition of each household's workers to be tracked through time. This, combined with the detailed simulation of swidden cultivation tasks, enables the model to capture the seasonal nature of labour use in swidden cultivation as well as the complementary nature of swidden and rubber tapping. The detailed accounting of labour use in the model also facilitates an assessment on the degree of dependency among households concerning labour availability. The model also tracks the genealogical links, which is probably the only approach enabling land (or property) inheritance to be simulated.

The model does not treat households as homogenous units. The heterogenous nature of households is an important property of human systems that deserves more attention in the study of land-use/cover changes. For example, simulation models capturing this heterogeneity allow assessments of the full impacts of events or policies and the associated distributional impacts, i.e., who will be adversely effected (Cameron and Ezzeddin, 2000). An example of this has been shown in this study. In particular, while increasing population pressure usually leads to decreasing fallow length, the differentiation of land holding among households is such that, even when the land has become scarce, some households are still able to practice long fallow

(section 4.4.3). Thus, households with different resource bases may and probably will have different reactions to external influences, such as increases in commodity price. An example of this can be seen from the simulation experiments applying different price levels and fluctuating prices of a commodity (section 5.4 and 5.5). In those experiments, although most households shift to rubber tapping when rubber price is high, some households continue to cultivate swiddens because they do not have mature rubber plots.

Another strength of the current model is the inclusion of a land tenure system. The significance of taking into account the land tenure system in land-use model lies in the fact that land is generally always under a form of tenure that determines who can get access to the land, and in some cases, sets the allowable types of land conversion. Thus the current model is a valuable tool to study the long-term implications of different land tenure systems. One potentially interesting exercise would be to compare the land tenure system currently implemented in the model, which gives households permanent 'ownership' to lands, with the one where lands are under control of the community instead of households (e.g. Cramb, 1989a). These two land tenure systems represent the types generally found among swidden agriculture communities in Borneo (Appell, 1986).

#### **6.4.2 Spatially explicit representation of landscape**

The current model includes factors that are well recognised as prime determinants in the selection of agricultural fields or locations for deforestation such as distance to the nearest transportation route. It also includes those factors that represent the 'social' motivation of households to locate swiddens close to other households' swiddens to facilitate working in a group (section 3.2.4 and 3.3.4.1). Such socially motivated factors are not specific to the Kantu'. Mackie (1986:51-58) reported a similar case among the Kenyah of East Kalimantan. The weighted site index used in this model is an effective way to evaluate the relative importance of various selection factors. It is important to note that the dynamics of landscape in this model is very sensitive to the assumption of weights in the site index, as shown in the sensitivity analysis (section 5.2). Different formulations of the weights will result in different courses of landscape development. An analysis on the implications of different sets



of the weights particularly on the spatial configuration of landscape would be a potentially interesting area to study.

Furthermore, the spatially explicit representation of the landscape permits an analysis of the importance of spatial factors in relation to the non-spatial ones in a dynamic way. This study has shown that preferences for land closer to the river and longhouse set the general pattern of agriculture expansion into primary forest. However, once all primary forest has been allocated and when the number of households continues to increase, the community will come to a stage where some households have only limited potential sites due to space and ownership constraints. At this stage, especially for households with small land holdings, the spatial consideration would be less important than vegetation type, given the assumed strong preference for long fallow practice<sup>1</sup>. For example, as an extreme case, a household is likely to clear a long fallow plot far from the longhouse rather than a short fallow plot near the longhouse. Such a dynamic perspective, which takes into account the state of households (i.e. land holding), would probably signal a caution for not overstating the importance of especially distance-related factors in analysing land-cover changes, particularly when this issue is viewed from the perspective of the 'agents'.

### **6.4.3 Model structure**

This study is society specific but most events or processes simulated in the model are general. Birth, marriage, death, adoption, household formation and household dissolution are events that are always expected to be in population models of this nature. Similarly, one would also expect to find the process of setting production targets (demand), selecting sites, estimating crop production and evaluating the production achievement in most agricultural land-use simulations. Of course, there are some rules that are specific to the Kantu' and communities having similar social system. However, the computer code used to implement the current model is flexible, so that rules can be readily replaced or added when necessary. For example, in the current version, the model deals with only one social structure (i.e.

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<sup>1</sup> Reflected by the far higher weight of vegetation factor compared with the other factors in the site index (see Table 3.4)

utrolateral<sup>2</sup>) but it can be extended to handle multiple social structures (see Keesing, 1975 for other types) by assigning the social structure to be an ‘attribute’ of a household (see Figure 3.4) and then specifying the procedures associated with each type of social structure. In this case, rules applied to each person would depend on the social structure affiliation of the person. Other examples demonstrating the flexibility of the model can also be seen from the experiments with different simulation scenarios presented throughout this thesis. This is an important point given that exploration *via* simulation scenarios is a useful approach to revealing the ‘hidden’ dynamics of the systems.

## 6.5 Main weaknesses of the model

### 6.5.1 Linking landscape pattern and vegetation dynamics

The spatial pattern of landscapes can affect numerous ecosystem processes, e.g. the spread and behaviour of fire (Turner and Romme, 1994). It can also influence the vegetation dynamics through mechanisms related to dispersion of seeds. Evidence suggests that the size and shape of patches can influence the establishment of primary forest species because as cleared patches become larger, the less likely the area in the middle of the patch will have ‘seed rain’ from the adjacent vegetation, since seeds have to travel a longer distance to reach the centre. This is particularly important because primary forest species generally have heavier seeds and correspondingly shorter dispersal capability (Brokaw, 1985; Vazques-Yanes and Orozco-Segovia, 1990). The effect of patch size on the establishment of species can be seen in the case of swidden cultivation in Long Segar, East Kalimantan. Here, in the vast agricultural clearings, species found in large numbers were mainly grasses, climbers and ferns with only a few seedlings of woody species (Kartawinanata *et al.*, 1984). In addition to size, one might also expect that the shape of patches would have some effects on the pattern of species establishment through border effect with adjacent vegetation. For example, a patch having an irregular shape with a long perimeter would be expected to have different seed rain from adjacent vegetation, compared to a patch with a regular shape and smaller perimeter.

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<sup>2</sup> Freeman (1992:14) defined utrolateral as “... a system of social organization in which an individual can possess membership of either his father’s or his mother’s birth group (i.e. the *bilek-family* among the Iban), but not of both at the same time”. As described in Chapter 2, the inheritance system of the Iban as well as the Kantu’ is derived from this principle of social organisation.

This study began with these 'ecological' issues as the primary focus, but I realised that these ecological processes would by themselves have limited explanatory value without taking into account the dominant forces shaping the spatial pattern of a landscape; i.e., the socio-cultural, economic and ecological considerations which underlie the households' land-use decisions. Thus, while this study has successfully represented the spatial expression of households' preference in locating swiddens, the implications of the preference for ecological succession are not simulated. In the current model, succession is determined solely from the duration since the last disturbance. I have not yet had the opportunity to explore the interactions between spatial patterns generated by 'human' disturbance and vegetation dynamics. This would be important because most ecological models relating spatial pattern and vegetation dynamics deal only with landscape under 'natural' disturbance such as fire (e.g. Green, 1989) or landscape whose pattern are exogenously imposed (e.g. Malason and Armstrong, 1996), but the combination of these are not generally considered.

### **6.5.2 Exclusion of labour migration**

Labour out-migration is a pervasive feature in rural areas around the world including most swidden agriculture communities (see Standing, 1985) and it is motivated by both economic (e.g. earning cash) and cultural (e.g. gaining social prestige) reasons. Labour migration can involve an extended period of absence; for the Iban of West Kalimantan, the period of absence ranges between 1 – 2 years (Wadley, 1997a:134). In general, an extended period of labour migration can affect the household economy primarily through reducing the availability of household's labour and adding to the household's income from remittance. The gender-specific nature of this type of labour migration, i.e. mostly young men, can potentially affect the swidden cultivation, given that men are needed for carrying out the heavy work, particularly the felling and clearing of large trees. However, studies show that the impact of male absence on the type of forest clearing varies depending on the local circumstances. Colfer (1985) and Heyzer (1995) reported a connection between male absence from households with shortened fallow period because of the women's inability to fell large trees. In contrast, Wadley (1997a) reported that in his study area the male

absence had no effect and this was attributed to the presence of mechanisms that compensated the loss of male labour including a functioning labour exchange system and the widespread use of chainsaw. Another important demographic effect of labour migration was reported by Padoch (1980) who found that a prolonged absence of males from home villages resulted in significantly lowered fertility, slower population growth and reduced pressure on a community's land resources.

Given the widespread occurrence of labour migration and its potential impacts on household economy as described above, the exclusion of labour migration in this model would most likely mean that the local labour availability has been overestimated. However, the consequence of this on the household economy and landscape can only be estimated using simulation experiments that includes labour migration based on a realistic scenario.

### **6.5.3 Assumption on constant socio-cultural and economic circumstances**

The simulations in this study were run for 75 years to allow a sufficient time for the dynamics of vegetation succession and the long-term implications of land inheritance rules to be analysed. This is a relatively long time for land-use models because the socio-cultural and economics circumstances are likely to change, and many assumptions may no longer hold after a certain period. Changes in circumstances can be triggered by endogenous (e.g. land scarcity due to population growth) or exogenous (e.g. road construction leading to a better access to market) events. In both cases, the households' are likely to make adjustments.

One crucial aspect within the model that is prone to change is the assumption that swidden cultivation has priority over cash cropping as presented in the 'default mode' (Chapter 4). This may well represent the Kantu' initial situation only until the 1980s, which corresponds to the first 30 years or so of the simulation, when the population was low and the study area was isolated. Dove (1981:85; 1985b:33) implied that the Kantu' adherence to swidden cultivation was partly cultural in a sense that they had a strong preference for a subsistence lifestyle. However, when a swidden community becomes more exposed to a market economy, profit considerations generally seem to become more important in land-use decision-

making. For example, there is a renewed interest in growing pepper in the study area following the end of isolation and the surge of pepper price in 1997. In this situation, it may be better to simulate the land-use decisions using a procedure that takes into account a form of cost benefit analysis of the various land-use options. The ‘flexible mode’ presented in Chapter 5 is in fact a step in this direction.

## **6.6 Future Work**

This study has produced an effective framework for integrating the demographic, socio-cultural, economic and ecological factors in land-use modelling. This modelling framework has successfully established major links among components of the system (e.g. persons, households, plots, etc.) and represented local institutions controlling the use of land and labour resources (e.g. land tenure, land inheritance, labour exchange, etc.). To improve the existing model, there are two key areas that need to be considered. First is an improvement of the treatment of biophysical/ecological processes as well as a more realistic representation of landscape. As indicated in the previous section, one important part of the model is the simulation of vegetation succession by taking into account the disturbance history as well as the spatial configuration of the surroundings. To deal with this, the major challenge is to formulate a model that has an underlying physiological basis but is simple enough for landscape-scale simulations, which also consider other socio-cultural and economic processes. Second, to improve the capability of the model to handle changing circumstances and in particular, allowing households to adapt to new circumstances. In this regard, a more ‘formal’ approach, based on microeconomic theories, could be used as the basis of a more ‘generic’ approach to the simulation of agricultural activities.

The main purpose of my study has been to demonstrate the feasibility of using individual-based modelling to represent agents of land-use changes; their family structures and their decision on agricultural practices to drive a model of landscape development. I feel that this has been done, and the lessons learnt applied in many current land management problems.

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# Description of the Appendices

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All appendices are presented in the accompanied CD-ROM. The organisation of the appendices is as follows.

## 1. Appendix I User Interface

- Sub-directory : CD\ UserInterface
  - Contents:
    - An executable file of the user interface for running simulations. To start the user interface, open file KantuSim.exe.
    - A manual on how to use this user interface. To view the manual, open file KantuSimManual.rtf.
    - Input files: Fertility.ini, Mortality.ini, Marriage.ini, FirstMarriage.ini, Reamarriage.ini, RiceConsumption.ini, InitLsc.ini, TopoMap.ini, RandWeight.ini. See the manual for further descriptions.

## 2. Appendix II Program Documentation

- Sub-directory : CD\ProgDoc
- Content:
  - Description of the main routines used to simulate the model. To view the program documentation, open file ProgDoc.rtf.

## 3. Appendix III Complete Program Coding

- Sub-directory : CD\ProgCode
- Content:
  - A 'DELPHI project' consisting of all coding files. The entire codes were organised in DELPHI *units*, which are saved as files with the '.pas' extension. The entire program structure can be viewed from DELPHI Version 3.0 by opening file KantuSim.dpr. Alternatively, the reader may open .pas files individually from a word processor application.

## 4. Appendix IV Thesis Document

- Sub-directory : CD\ThesisDoc
- Content:
  - Electronic copy of the thesis (TitleDoc.rtf and ThesisDoc.rtf). Note that due to the large size of this file, some of the figures may not be displayed correctly.